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An Assessment of Development Options, Management Strategies, and Climate Scenarios for the Nile Basin

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The authors find Nile Basin investigations as rewarding as they were at the onset, and they are grateful for the opportunity to contribute to a better understanding of important basin-wide issues.

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1. Context and Scope

The Nile Basin has come to many crossroads in its long history. This one, however, is about rapidly rising populations, economic pressures, and future growth opportunities. How can the Nile continue to meet the needs of its people in ways that are no less sustainable than they are pragmatic? This question is at the forefront of an unfolding initiative by the Nile Basin Governments to set forth equitable and lasting water development and utilization agreements. Such is the context of the assessment described herein: to evaluate the merits and tradeoffs of various water development options, management strategies, and climate scenarios to support the Nile Basin nations with technically-sound information.

The assessment uses modern technology and advanced analysis methods. However, after all the technical investigations and detailed interpretations, there is an unmistakable conclusion. The key to sustainable future growth and opportunity for all Nile Basin nations is to recognize and respect the unity of the river that flows without regard to national boundaries.

This document includes six sections and four appendices. Section 2 provides an overview of the Nile Basin regions, focusing on their unique hydrologic features and development opportunities. Section 3 describes the water development, management, and climate scenarios to be investigated and explains their attributes and rationale. The scenarios cover a wide range of options from minimal basin development and no cooperative water management to full development and basin-wide cooperation. Section 4 outlines the assessment methodology and the models employed. The assessment results are discussed in Section 5 relative to three criteria: water shortages, energy generation, and river flow patterns. This section also serves as **a synopsis** for the reader who is more interested in a broad overview rather than the detailed assessment results. Section 6 provides the scenario implications by region, helping to clarify the regional and basin-wide implications of each development project, management strategy, and climate scenario.

To facilitate reading the document, figures and tables are included at the end of each section. Supporting data and results are presented in the appendices. More specifically, Appendix A includes tables of various development project characteristics; Appendix B presents and discusses detailed results for the baseline climate, comparing the basin response relative to average, extreme, and seasonal statistics and sequences; Appendices C and D include similar information for the other two climate scenarios.

2. Nile Basin Overview

The Nile River Basin is spread over ten countries covering an area of about 3.1 million km^2, or approximately 10 percent of the African continent. The river discharge per unit drainage area is small, and almost all of the Nile water is generated from only 20 percent of the basin, while the remainder is in arid or semi-arid regions. Figures 1a, 1b, and 1c provide a composite map of the Nile Basin encompassing the five main regions: (a) the Equatorial Lake sub-basin within the countries of Uganda, Tanzania, Kenya, Rwanda, Burundi, and Congo, (b) the Sudd, the Bahr el Ghazal, and the Sobat River Basin (in Sudan and Ethiopia), (c) the White Nile (in Sudan) connecting the Sudd region with the Blue Nile, (d) the Blue Nile and Atbara Rivers draining parts of Ethiopia, Eritrea, and Sudan, and (e) the Main Nile flowing through Northern Sudan and Egypt. Each region has distinct hydrologic features, water use requirements, and development opportunities. The purpose of this section is to briefly outline these elements and provide the background and rationale for the water resources development and management scenarios to be investigated.

Equatorial Lake Region

The Equatorial Lake region encompasses Lakes Victoria, Kyoga, and Albert and their drainage basins. The lakes are connected through the Victoria and Kyoga Niles and form a cascade containing vast quantities of water. Table A.1 (Appendix A) compiles recorded minimum, mean, and maximum lake levels; storage volumes; and outflows. These statistics show that the combined lake storage capacity (within the historical fluctuation range) is 260 billion cubic meters (bcm), 215 bcm of which pertain to Lake Victoria. Lake Victoria is regulated by the Owen Falls hydroelectric Dam, while Lakes Kyoga and Albert are presently unregulated. The steep topography of the Victoria and Kyoga Niles is conducive to hydroelectric development. In addition to Owen Falls and its extension, Figure 1 and Table A.2 reference five other potential hydroelectric sites that would raise the total generation capacity to 2300 MW.

Sudd, Bahr el Chazal, and Sobat

Exiting Lake Albert, the Nile flows north to Nimule at the Ugandan-Sudanese border. From here, it changes name from Albert Nile to Bahr el Jebel, receives the contribution of several tributaries known as Torrents, reaches Mongala, and soon thereafter enters the Sudd. Below Mongala, the river enters the Sudd swamps, spills over its banks, and inundates the adjacent flood plains. In the Sudd, evaporation exceeds rainfall by about 1300 millimeters per year, causing most of the spilled water to evaporate. At Malakal, where the river and its bifurcations emerge from the Sudd, only half of the Mongala flow remains.

The seasonal cycle of wetland flooding and drying is a key element of the ecology and the economy of the Sudd. Howell et al. (1988) and Sutcliffe and Parks (1999) explain that the swamps are either permanent wetland areas (i.e., wetlands that remain flooded throughout the year) or seasonal wetland areas (i.e., wetlands that are flooded during the rainy season and uncovered during the dry season, from December to April). Seasonal swamps are most valuable to the local economy as they support cattle grazing during the dry season.

The Jonglei Canal was first proposed (Garstin, 1904) as a water conservation project to reduce evaporation in the Sudd and augment the Nile flow. In Phase II of the project, the Canal would divert up to 43 million cubic meters per day from Bahr el Jebel at Bor, before significant overbank spillage would occur, by-pass the swamps, and discharge into the Sobat River immediately before its junction with the White Nile. From a water conservation standpoint, the canal benefit would depend on its operating rule (partitioning the flow between the Bahr el Jebel and Jonglei) as well as on the flow regulation exercised by Lake Albert.

The Bahr el Ghazal and its tributaries (Bahr el Arab, Lol, Jur, Tonj and others) drain an area of more than 500,000 square kilometers. Over-bank spillage occurs extensively in the basin, and evaporation is so significant that when the river joins Bahr el Jebel at Lake No, its flow contribution is minimal.

Water conservation projects have also been proposed for the Bahr el Ghazal river basin. The potential water benefits from these projects are estimated at 5 to 8 bcm per year (UNDP, 1981, Fahmy and Fahmy, 1981), but these estimates need to be revised with more detailed data.

Below Lake No, the river is known as the White Nile and flows eastward until it joins the Sobat River, a few kilometers upstream of Malakal. Sobat's main tributaries, Baro, Akobo, and Pibor, drain portions of Ethiopia and southern Sudan. Before joining Pibor, Baro spills some of its water to the adjacent Machar Marshes (Jonglei Investigation Team, 1954). Water conservation projects have been proposed to minimize spillage and augment the flow of the White Nile.

White Nile

From Malakal, the White Nile flows north toward Khartoum, a distance of approximately 840 kilometers, on a very mild channel slope with no significant additions to flow. The Gebel el Aulia Dam dominates this part of the basin. The dam is located 40 kilometers upstream of the confluence with the Blue Nile, but its backwater effects (on river stage and flow) extend 600 kilometers upstream to Melut. The reservoir has a storage capacity of 3.5 bcm and its principal purpose is to raise the river stage and facilitate the pumping of irrigation water. Evaporation losses are estimated at 3.5 bcm per year, and current irrigation withdrawals amount to 1.5 bcm per year

Blue Nile and Atbara

The Blue Nile originates from Lake Tana far up in the Ethiopian highlands and spirals down toward Sudan in deep gorges. The distance from Lake Tana to the Ethiopian-Sudanese border (Diem) is 900 river-kilometers, and the elevation drop is nearly 1300 meters. At the border, the river enters the Sudanese plains and flows toward Khartoum for another 700 kilometers of mildly sloped terrain. The climate of the Ethiopian plateau is influenced by the migration of the Inter-tropical Convergence Zone (ITCZ) which produces heavy rains from

June to September and dry conditions for the rest of the year. As a result, the Blue Nile is highly seasonal with most flow occurring from July to October.

With the exception of two relatively small Sudanese reservoirs (Roseires and Sennar) and a hydroelectric weir below Lake Tana, no other regulation projects exist along the Blue Nile. However, the topography of the basin in Ethiopia can support a series of major hydroelectric and storage projects (U.S. Bureau of Reclamation Study, 1964). The characteristics of these projects (i.e., Lake Tana, Karadobi, Mabil, Mendaia, and Border) and those of Roseires and Sennar are summarized in Table A.3 (Appendix A). The table shows that full hydropower development in Ethiopia could create 62 bcm of combined reservoir storage and 5700 MW of hydroelectric power capacity. The benefits and implications of such projects are important for Ethiopia and all Nile Basin Nations.

Presently, large scale irrigation takes place only in Sudan below Sennar. In fact, the primary purpose of Roseires and Sennar is to secure and divert this quantity to the irrigation areas.

The last tributary of the Nile is the Atbara River which drains parts of Ethiopia (north of Lake Tana), Eritrea, and Sudan. Atbara flow is highly seasonal, similar to that of the Blue Nile. The river provides water for irrigation (at 1.5 bcm annually) and energy generation through the Khashm el Girba reservoir (Table A.3).

Main Nile

The Main Nile encompasses the reaches from Khartoum to Wadi Halfa (1500 kilometers), Lake Nasser (400 kilometers), and the Egyptian Nile from Aswan to the Mediterranean Sea (1200 kilometers). In this part of the basin, rainfall is minimal and evaporation losses are high. The average inflow to Lake Nasser is 84 bcm per year, but in this century, actual inflow has varied from a 125 bcm per year high to a 40 bcm per year low. The marked inflow variability underscores the importance of Lake Nasser as an overyear storage reservoir. The 106 bcm of active lake storage (between 147 and 178 meters) provides muchneeded security against severe droughts. When water levels exceed 178 meters, the Toshka spillway diverts water to the desert to avoid downstream flooding and channel erosion.

The old Aswan Dam is located six kilometers downstream of the High Aswan Dam and provides diurnal flow regulation. The power stations of the two dams have a combined power capacity of 2721 MW (Table A.4). At present, Egypt uses 55.5 bcm of water per year, primarily for irrigation. The water is delivered to farms through an elaborate network of irrigation canals. However, as with all Nile Basin Nations, water demands continue to rise.

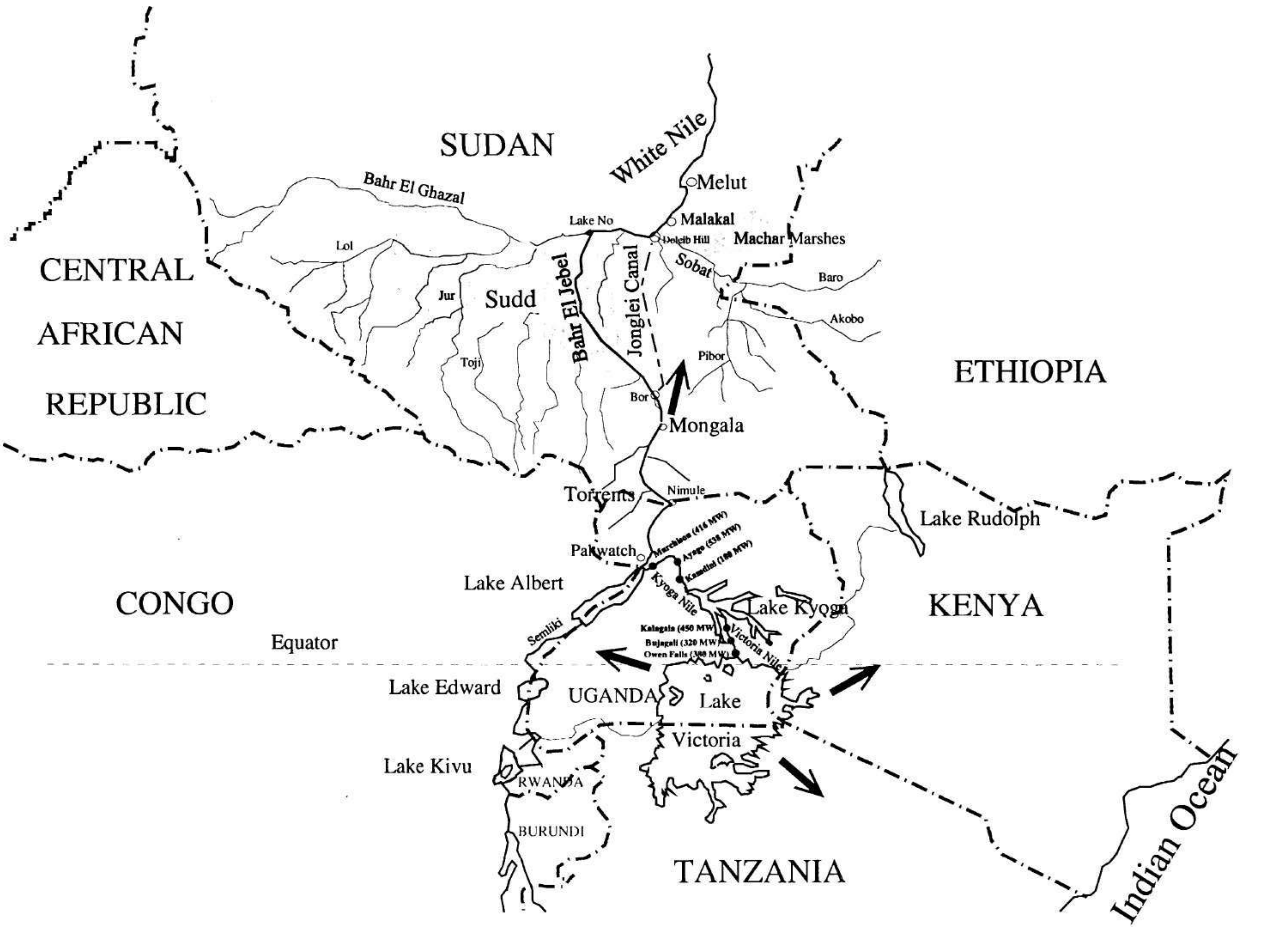


Figure 1a: Nile Basin: Equatorial Lakes and Sudd

Figure 1b: Nile Basin: Blue Nile and Atbara River

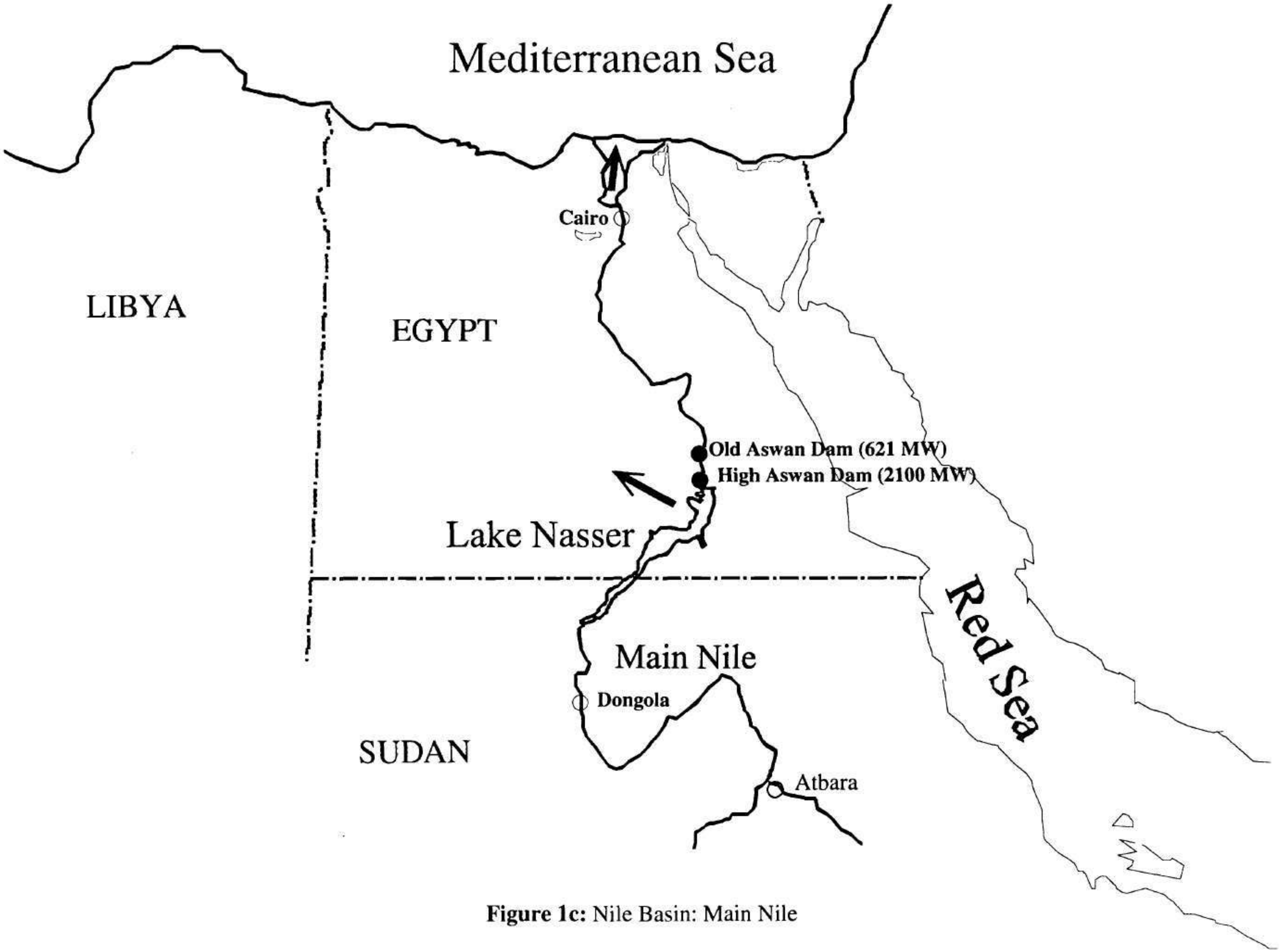


Figure 1c: Nile Basin: Main Nile

3. Water Development and Management Scenarios

The rationale of the basin development and water allocation scenarios is to provide a broad understanding (a) of the implications associated with water use increases and potential climate changes and (b) of the benefits associated with various basin development projects and water management strategies.

The water development and management scenarios are presented in Table 1 and are arranged in a matrix by two main attributes. The first attribute describes the water demand/use targets and distinguishes three levels--current demand targets, low demand targets, and high demand targets. The second characterizes the degree of basin development and project coordination, and includes (1) current condition and no cooperation (Scenario I), (2) eastern (Blue) Nile development and sub-basin coordination (Scenario II), (3) southern (White) Nile development and sub-basin coordination (Scenario III), and (4) basin-wide development and full cooperation (Scenario IV).

Demand Target Levels

The water demand targets represent increases over current water uses and are shown on Table 1 by sub-basin or country. More specifically, these water withdrawals occur at the locations indicated on Figure 1 (by the arrows). These correspond to the Lake Victoria basin, Sudd (at Mongala), Gebel el Aulia, Lake Tana basin, Karadobi basin, Mabil basin, Border basin, Sennar, Khashm el Girba, Lake Nasser, and downstream HAD. Current water use levels in Sudan are estimated at 1.5 bcm from Gebel el Aulia, 15.32 bcm from Sennar, and 1.38 bcm from Khashm el Girba. Current Egyptian water use is 55.5 bcm downstream of the HAD. Elsewhere in the basin, current water withdrawals are considered minimal.

Table A.5 (Appendix A) indicates the basin locations from which the scenario withdrawals take place. The annual withdrawal targets are disaggregated into seasonal sequences based on the growing season(s) of each region, typical crop consumptive use, and seasonal distribution of rainfall deficiency. The demand locations included in this investigation are considered to be representative of regions with rapidly rising water use stresses. However, these scenarios are not exhaustive, and other locations and promising target distributions can also be investigated.

Basin Development and Management Options

Scenario I represents current basin development conditions. In this scenario, the Equatorial Lakes are unregulated, there are no wetland projects, and there are no sizable reservoirs along the Blue Nile in Ethiopia. Existing reservoirs include the Owen Falls Dam in Uganda; the Gebel el Aulia, Sennar, Roseires, and Khasm el Girba in Sudan, and the High/Old Aswan Dams in Egypt. In addition to these projects, Scenario II assumes the construction of five Ethiopian reservoirs at Lake Tana, Karadobi, Mabil, Mendaia, and Border. By contrast, Scenario III focuses on developments along the southern (White) Nile including several hydropower facilities along the Victoria and Kyoga Nile reaches, wetland conservation projects in the Sudd, the Bahr el Ghazal, and the Sobat River basin (Machar Marshes), and full regulation of the Equatorial Lakes. No Ethiopian developments are considered in this scenario. Lastly, Scenario IV includes the concurrent implementation of all previous projects as well as basin-wide reservoir coordination regardless of location.

The characteristics of the aforementioned reservoirs and hydropower facilities are reported in Appendix A. The modeling assumptions regarding the wetland projects in Scenario III are as follows: The Bahr el Ghazal and Machar Marshes projects could augment the White Nile flow by a combined amount of 4.75 bcm per year. Hydrologic information about these areas is scant, and water balance assessments are somewhat uncertain. However, 4.75 bcm per year is less than half of what has generally been estimated as a potential yield from these sites (Chan and Eagleson, 1980, El-Hemry and Eagleson, 1980, UNDP, 1981, Fahmy and Fahmy, 1981, Sutcliffe and Parks, 1999). The temporal distribution of the water benefit is assumed to follow the seasonal runoff pattern of the Bahr el Ghazal and Baro river basins and is added to the flow at Malakal. The operation policy of the Jonglei Canal in Scenario III aims at maximizing the water gains from the Sudd. More specifically, if the flow at Bor is less than or equal to 50 million cubic meters (mcm) per day, it passes entirely through the

Bahr el Jebel. Flows in excess of 50 mcm per day pass through the Jonglei Canal up to its capacity of 43 mcm per day. Flows in excess of 93 mcm per day are diverted back through Bahr el Jebel. All Equatorial Lakes are regulated with the focus on local water uses. Assuming current water use conditions, the previous operation of the Jonglei Canal would reduce Sudd evaporation by an average of 7 bcm per year.

Lastly, Scenario IV introduces basin-wide cooperative management strategies among all development projects and storage facilities. More specifically, in addition to meeting local objectives, the Equatorial Lakes are now regulated to (a) maintain the seasonal wetlands at the Sudd while reducing evaporation losses, and (b) augment water supplies in the event of downstream droughts. Similarly, the regulation of the Blue Nile projects aims at reducing floods at Khartoum and creating a more uniform and manageable flow regime.

Climate Scenarios

The basin response sensitivity to climate changes is assessed for three climate scenarios. These include a baseline scenario reflecting historical hydro-climatic conditions, and two future climate scenarios simulating climate conditions that may occur at 2020 and 2050 as a result of a 1% annual increase of atmospheric greenhouse gases. The development of these scenarios is further explained in the following section. Figure 2 shows the annual inflow expected under each of these scenarios for different Nile sub-basins. It is notable that the climate response of the southern and eastern Nile regions is different and that future climates become progressively drier.

Table 1: Nile Basin Water Development and Management Scenarios

System Configuration

	Current Condition	Full Development in Eastern Nile (Ethiopia/Sudan)	Full Development in Southern Nile (Wetland Projects + Eq. Lake Regulation)	Basinwide Cooperation
Scenario I	Yes			
Scenario II	Yes	Yes		
Scenario III	Yes		Yes	
Scenario IV	Yes	Yes	Yes	Yes

Note 1: Wetland Projects imply a 12 bcm annual increased yield, 4.75 bcm of which is attributed to the Machar Marshes and Ghazal projects, and the rest to Jon
Note 2: Full Development in Ethiopia includes projects at Lake Tana, Karadobi, Mabil, Mendaia, and Border.

Water Withdrawal Targets (Billion Cubic Meters per Year)

	Eq. Lake Region	Sudan	Ethiopia/Eritrea	Egypt
Current Condition	0	18.5	0	55.5
Low Demand Increase	2.5	21	10	58
High Demand Increase	5	23.5	20	60.5

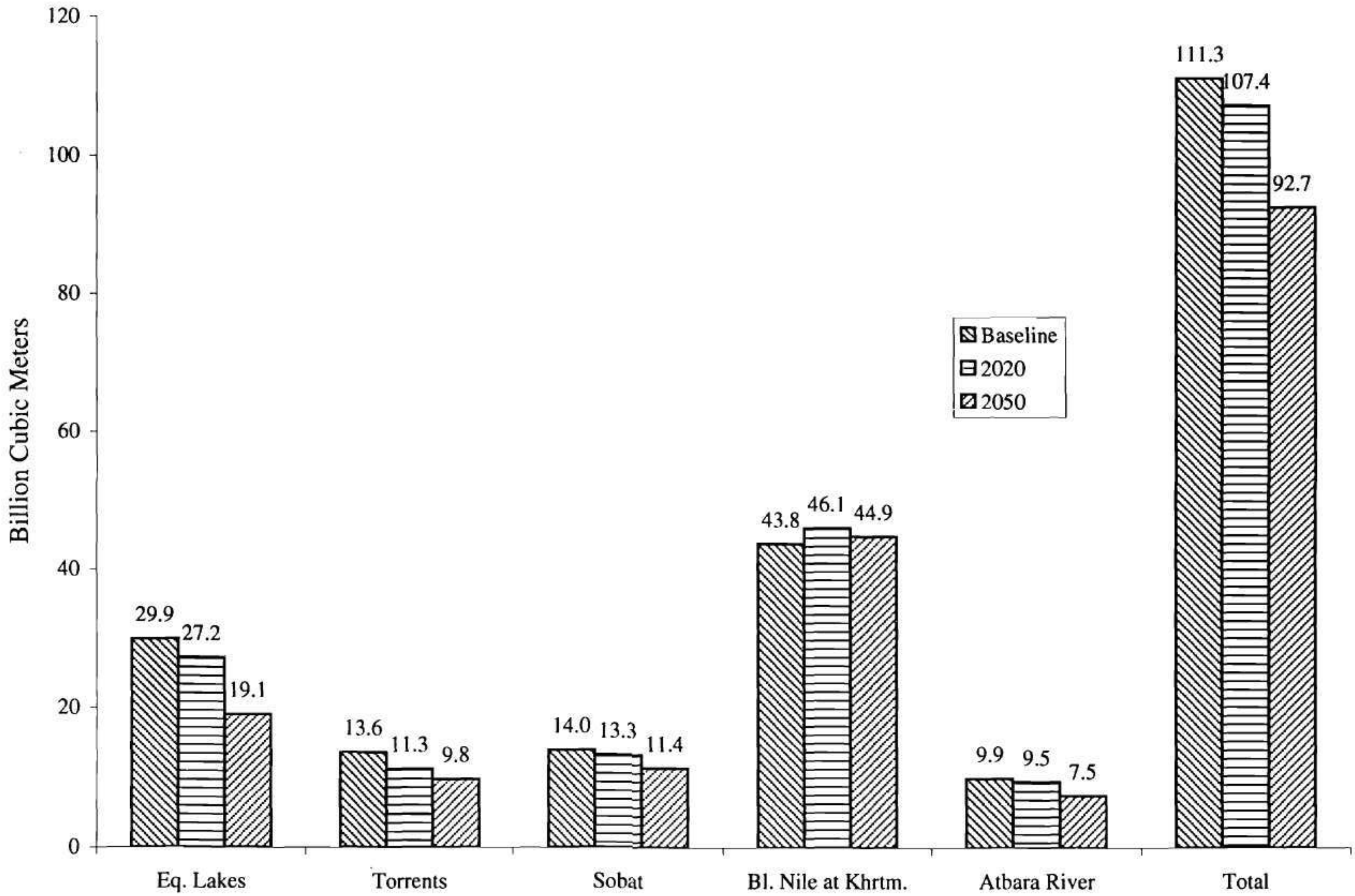


Figure 2: Annual Flow Comparison for Different Climate Scenarios

4. Assessment Methodology

Assessing the basin response to the previously described scenarios follows a three-step process: data collection, model development, and scenario assessment investigation. Because the Nile Basin is so extensive and intricate, each one of these steps represents a multi-year effort.

Data Base

The data used for this assessment fall to three major categories: hydrologic data, reservoir and other project data, and demand data. Hydrologic data include rainfall, temperature, evaporation, and streamflow for different climate scenarios. Reservoir and other project data include capacity-elevation-area curves, tailwater curves, spillway and other hydraulic outlet features, hydropower plant characteristics (number and type of turbines, turbine power-net head-discharge curves, and hydraulic losses), and diversion canal capacities. Demand data include current and future agricultural water use requirements, flood stage thresholds, and typical daily/seasonal power demands.

This extensive database has been assembled from many sources, the most important of which are Nile Basin governmental agencies with which the authors have collaborated for several years. Among these agencies are departments of water development, ministries of water, hydrometeorological services, agricultural experiment stations, and power utilities in Tanzania, Uganda, Kenya, Ethiopia, Sudan, and Egypt. This interaction has taken place directly or through international organizations such as the Food and Agriculture Organization of the United Nations (FAO), international aid organizations, and the World Bank. Data and relevant information have also been obtained from a variety of other sources including the Nile Basin Volumes and Supplements (Hurst and associates, 1931, 1938, 1946, 1950, 1966), United States Bureau of Reclamation Study (1964), the Proceedings of the Nile 2002 Conference Series, and numerous published books and journal articles.

Models

The assessment uses three coupled models. The first model is the HadCM2 General Circulation Model of the British Hadley Climate Center. This GCM is used to generate three climate scenarios. The baseline HadCM2 scenario covers the historical period from January 1, 1940, to December 31, 1989. Two additional climate scenarios (labeled "2020" and "2050") were generated using HadCM2 assuming that atmospheric greenhouse gases increase at 1% per year. Each of the future climate runs covers an analogous, 50-year period.

The second model is the Nile Forecast System (NFS) developed by the National Weather Service (NWS). This model is used to generate "baseline," "2020," and "2050" streamflows at 9 basin locations. For the future climate, the historical NFS precipitation and evapotranspiration data were modified using the GCM output to develop consistent atmospheric forcing. The generation of the streamflow scenarios was conducted by Riverside Technologies, Inc., and is detailed in a report submitted to the National Weather Service in December 1999.

The third model used in the assessment is the Nile Decision Support System (Nile-DSS) which integrates several sub-basin models currently used by Nile Basin agencies for operational and planning purposes. The model and its applications are discussed in a series of published and forthcoming articles (1996, 1997a, 1998a,b,c, 1999a,b,c). What follows is a brief description of the modeling components.

The Nile-DSS is designed to reproduce the Nile Basin response to various hydrologic conditions development scenarios, and operational strategies. The primary model functions include inflow forecasting, river and reservoir routing, and reservoir control.

The purpose of the inflow forecasting component is to predict the 10-day inflows several months into the future. The forecasted inflows are presented as equally likely realizations reflecting historical (and future climate) inflow characteristics such as seasonal and long-term variability. Forecasts are generated for all entry nodes of the river network including Lakes Victoria, Kyoga, and Albert, Torrents, Bahr el Ghazal, Sobat, Lake Tana, Karadobi, Mabil, Mendaia, Border, Roseires, Sennar, Dinder, Rahad, and Khasm el Girba.

The river and reservoir routing components simulate the movement of water through the river reaches and quantify transmission losses and time lags. The routing models are based on statistical or physically-based relationships (depending on available information) and incorporate model error characterizations. Reservoir and lake outflow through hydropower facilities and spillways is modeled with sufficient detail for use in operational applications.

The purpose of reservoir control is to determine release sequences from each system reservoir such that sub-basin and basin-wide objectives are met as best as possible. System objectives include meeting water supply targets and avoiding water shortages, minimizing losses, maintaining land use patterns (Sudd), regulating river flows, avoiding spillage, and generating as much firm and average energy as possible. The task of the reservoir control module is complicated by the system size, non-linear response, and intrinsic uncertainties. The optimization operations are carried out by the Extended Linear Quadratic Gaussian (ELQG) control method (developed by *Georgakakos and associates, 1987, 1989, 1993, 1997b,c,d* , a trajectory iteration optimization algorithm suitable for multidimensional, dynamic, and uncertain systems.

Scenario Assessment

The Nile-DSS models are designed for operational system management. Namely, given a particular system configuration, the Nile Basin authorities can use them to determine and implement desirable ten-day reservoir operation policies. Operational models, however, cannot assess the long term implications of management policies, nor can they determine the relative merits of different system configurations. To carry out these investigations, an assessment module was developed and added to the Nile-DSS.

The assessment process (Figure 3) begins with the selection of a target demand level, a specified system configuration (i.e., a project combination to be considered in the current run), and a project coordination policy (such as no cooperation, sub-basin level cooperation, or basin-wide cooperation). Then, for each ten-day interval of the assessment periods (baseline, "2020," and "2050"), the assessment module activates the Nile-DSS models to (a) generate inflow forecasts (assuming knowledge of only current and past hydrologic conditions), (b) determine reservoir releases, (c) simulate the water movement through all system reaches using actually observed inflows, and (d) record reservoir levels, energy generation, water shortages, flow discharges, spills, wetland areas, and other quantities of interest. The process is repeated at the next and all subsequent ten-day intervals until the end of the assessment horizon. At the completion of the forecast-control-simulation process, the Nile-DSS generates statistics of all recorded sequences and develops a comprehensive database for comparative scenario analysis.

The following are unique features of the Nile decision support system:

- Explicit treatment of hydrologic and model uncertainty;
- Detailed representation of system dynamics and water uses;
- Ability to develop and test sub-basin and basin-wide management strategies; and
- High computational efficiency combined with user-friendly features (running on personal computers).

The Nile-DSS design concept is to characterize the implications of various basin development and management options rather than to rank them. In this context, the operative term of the Nile-DSS is to *support* the information needs of the Nile Basin stakeholders in their historic effort to establish equitable and lasting agreements.

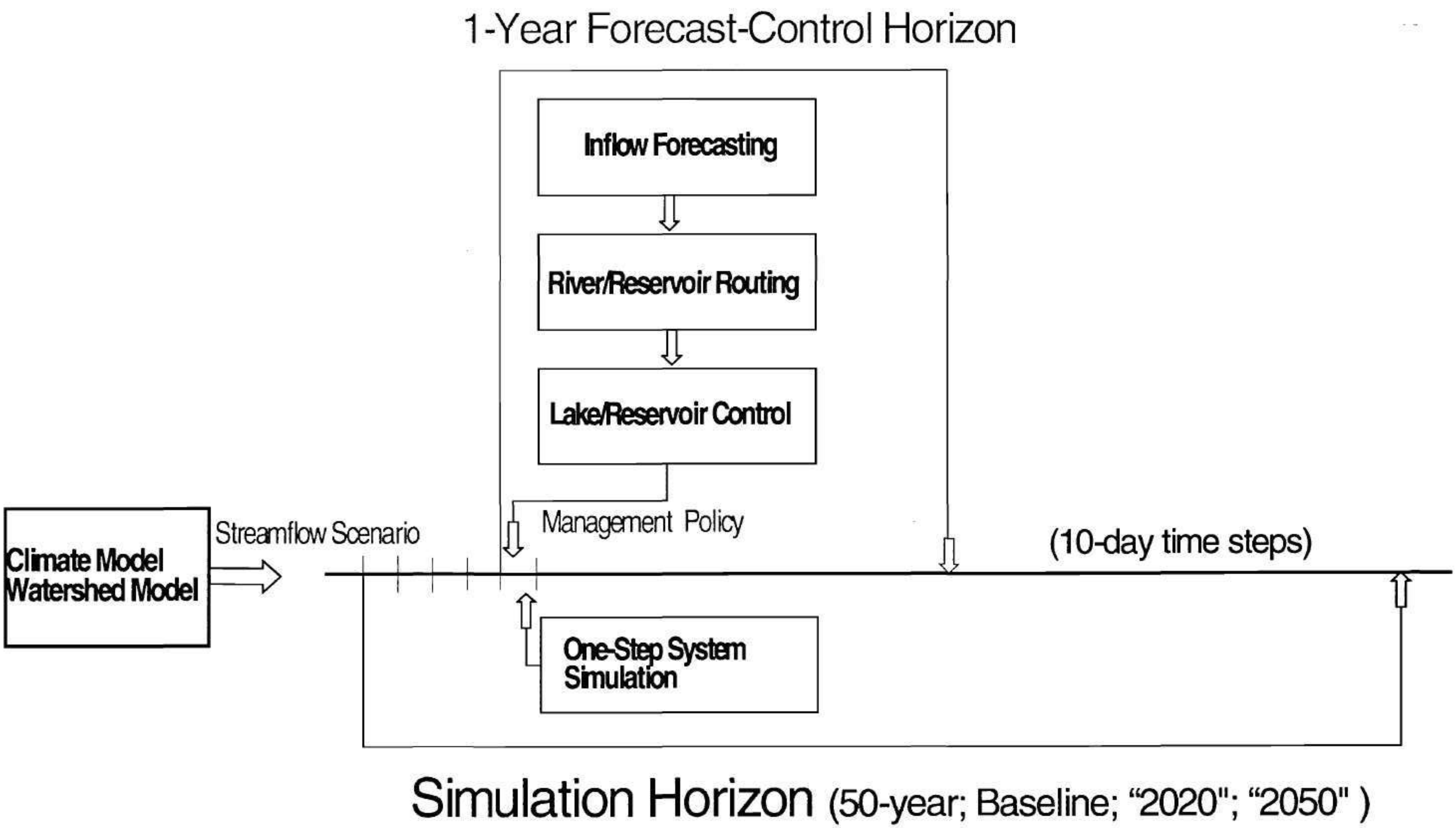


Figure 3: Scenario Assessment Process

5. Scenario Assessments

The decision support system described in Section 4 was used to assess the Nile Basin response to the development and water management scenarios defined in Section 3. In the following discussion, the assessment results are summarized relative to the following criteria:

- Water supply deficits by country (or region);
- Energy generation (average and firm) at the major hydropower facilities; and
- River flow availability at representative locations throughout the basin.

This section is an executive summary of the assessment results. The presentation focuses on annual average quantities and includes four sections associated with the four development and management scenarios in Table 1. Each section evaluates the impacts of climate and demand change on the various water uses and regions. More detailed information on the entire frequency distribution of the basin response is provided and discussed in the appendices.

5.1 Development Scenario I

This scenario represents the current basin condition with no further development. Deficits occur when there is insufficient water to satisfy the water supply targets assigned to a region by a particular scenario. The underlying assumption is that upstream targets are satisfied first, as fully as possible. Other deficit management rules can also be implemented, but this approach provides (1) a reliable estimate of the expected basin-wide deficits, and (2) a rational basis for developing alternative deficit re-allocation rules. Figure 5.1.1 compiles average annual deficits by (1) country or sub-region, (2) demand level (current, low, and high), and (3) climate scenario (baseline, 2020, and 2050).

Sensitivity of Water Supply Deficits to Demand and Climate Changes

The basin sensitivity to **demand target increases** can be assessed by comparing the three graphs in Figure 5.1.1, from top to bottom, focusing on a particular climatic scenario (for example, the baseline). The graphs show that deficits increase in all regions, except for the Equatorial Lake countries where deficits (relative to annual withdrawals of 2.5 and 5 billion cubic meters) are negligible. Under current basin development and in view of the strong Blue Nile seasonality, Ethiopia can only use approximately 50% of its allocated share. Likewise, Sudan is unable to utilize any additional share of the Blue Nile flow. Egypt's deficit increases by 3 and 7 billion cubic meters relative to the baseline case. It is noted that the baseline climatic scenario should not be viewed as representative of the historical hydro-climatic conditions. Rather, it represents the GCM-generated hydro-climatology *for* the historical period. This is the reason why Egypt experiences a 6.3 billion cubic meters deficit at the current demand conditions. Thus, these results are only meaningful as *relative changes* from the baseline, not as absolute amounts. Due to the way withdrawals are scheduled to occur (upstream regions withdraw their shares first), the Egyptian deficit represents a surrogate deficit measure for the entire basin.

Each graph in Figure 5.1.1 also presents the water supply deficits associated with the **baseline, 2020, and 2050 climate scenarios**. The differences between the baseline and the 2020 scenarios are small. However, the 2050 scenario implies significant water shortages, mainly due to runoff reduction in the Equatorial Lake region. These reductions (relative to the baseline climate) primarily affect Egypt and amount to 4, 6.5, and 7.5 billion cubic meters per year for the current, low, and high demand scenarios respectively. Deficits, albeit small, also begin to occur at the Equatorial Lake region for the 2050 climate scenario.

Sensitivity of Energy Generation to Demand and Climate Changes

Figures 5.1.2 and 5.1.3 summarize the basin response relative to annual average and firm energy generation, the latter being the lowest annual energy output over the assessment period. Most of the hydropower output in this scenario (more than 75% of the total) is generated by the Aswan hydro complex.

The **annual average energy output is expected to decrease as demand targets increase** (vertical graph comparison in Figure 5.1.2). In Uganda (Victoria Nile), the reduction is estimated at 9% at each new demand target level. Due to considerably higher water withdrawals in the Blue Nile Basin, energy generation in Sudan (Roseires, Sennar, and Khasm el Girba) is reduced by 25% at the low demand target level and by an additional 13% at the high demand target level. The Aswan hydro complex experiences a 15% loss of energy at the low demand target level, and an additional 9% at the high demand target level. The corresponding percent reductions of the total system output are 16% and 9.5%.

As with water supply, the energy outputs of the first two **climate scenarios** are not appreciably different. However, the energy output of the 2050 climate scenario is 17% to 19% less than that of the other two scenarios.

System **firm energy generation** is significantly affected by both demand increases as well as potential climate changes. Total, basin-wide firm energy is approximately 50% of the average annual output for the baseline climate and current demand targets. At the low and high demand target levels, however, the ratio of the firm to the average energy output decreases to 46% and 42% respectively. Furthermore, for the 2050 climate scenario, firm energy is 36% of the average energy at the current demand target level, 28% at the low demand target level, and 22% at the high demand target level. Generally, firm energy generation is more sensitive than average energy to prolonged droughts that may occur as a result of increased demands or drier climates. Herein, the two factors occur simultaneously, exacerbating the adverse basin response.

Sensitivity of River Flow to Demand and Climate Changes

River flow sensitivity is discussed for four river basin locations (Figure 5.1.4). These include the exit of Lake Albert (representing the outflow from the Equatorial Lake system), Malakal (representing the response of the Sudd and the Sobat river basin), Khartoum (representing the outflow of the Blue Nile basin), and Dongola (representing the inflow to Lake Nasser).

For a particular climate scenario, river flow decreases as **demand targets increase** (vertical graph comparison) from current to high levels. At some locations (e.g., at Lake Albert and Malakal), the flow reduction is approximately equal to the demand increase of the corresponding sub-basin, while at others (e.g., at Khartoum and Dongola) the flow reduction is less because actual withdrawals fall short of the demand targets (as previously discussed). A notable observation relates to the flow at Malakal. Despite the significant reduction of the Lake Albert outflow (of 2.2 and 4.4 billion cubic meters relative to current demand conditions) and the additional Sudd withdrawals (of 1 and 2 billion cubic meters at the low and high demand target scenarios), the flow at Malakal exhibits milder reductions (of only 1.1 and 2.1 billion cubic meters per year). This flow recovery occurs because as upstream withdrawals increase wetland flooding becomes less severe and less frequent and Sudd evaporation decreases. Comparing the current with the high demand target scenarios, the annual Sudd evaporation reduction is estimated at 4.5 billion cubic meters.

Regarding the basin response across the **climate scenarios**, river flow is expected to decrease at Lake Albert, Malakal, and Dongola, and somewhat increase at Khartoum. The highest reduction is projected for 2050 and for the Equatorial Lake system (about 9 billion cubic meters annually). At the same climate scenario, due to the positive Sudd feedback and the increase of the Blue Nile flow, the flow reduction at Dongola is also about 9 billion cubic meters annually.

5.2 Development Scenario II

This scenario includes the construction of major storage and hydroelectric projects on the Blue Nile in Ethiopia (i.e., at Lake Tana, Karadobi, Mabil, Mendaia, and Border), with no other development occurring elsewhere in the basin. The new projects are operated to minimize the Ethiopian and Sudanese interests (i.e., to meet the sub-basin water supply targets and maximize energy generation.

Sensitivity of Water Supply Deficits to Demand and Climate Changes

Figure 5.2.1 quantifies the basin ability to satisfy the water supply demands for different climate scenarios. A comparison of this figure with Figure 5.1.1 (of Scenario I), leads to several notable observations:

- Ethiopian and Sudanese water supply deficits are drastically reduced relative to Scenario I. In fact, deficits are practically eliminated at the current and low demand target levels, while they are reduced by 75% at the high demand targets. This beneficial outcome for Ethiopia and Sudan is principally due to the availability of sizable reservoir storage in Ethiopia. Cumulatively, the proposed Ethiopian projects would create approximately 62 billion cubic meters of active reservoir storage and would enable significant water transfers from wet to dry seasons as well as wet to dry years.

- As the end water user, Egypt would experience higher water deficits with respect to Scenario I. In percent form and depending on the demand and climate scenario, Egyptian deficits would increase by 50% to 80%. The most adverse situation for Egypt would occur for the 2050 climate scenario and the high demand target level. In this case, the average annual deficit would reach 33.6 billion cubic meters, an amount representing more than 50% of the annual Egyptian demand target of 60.5 billion cubic meters.

- Lastly, for the Equatorial Lakes region, Scenarios I and II are identical, leading to the same low deficits.

Sensitivity of Energy Generation to Demand and Climate Changes

Figures 5.2.2 and 5.2.3 summarize the basin response relative to annual average and firm energy generation. The most striking difference with Scenario I is the multifold energy increase of the Blue Nile Basin (Ethiopia/Sudan). These and other observations are noted below:

- Blue Nile energy output exhibits a 20-fold increase as a result of the Ethiopian hydropower projects. At the current demand level, the Blue Nile energy output exceeds 30,000 GWh per year, an amount representing 75% of the total basin energy generation.

- Blue Nile energy generation decreases as Ethiopian and Sudanese demand targets increase. This reduction is 20% (or about 6,000 GWh per year) at the low demand target level and 23% (or 5,600 GWh per year) at the high demand target level. Thus, irrigation withdrawals in the Blue Nile basin have an adverse effect on hydropower. Roughly, this tradeoff implies the loss of 500 GWh per year for every billion cubic meter of water dedicated to irrigation.

- Higher water withdrawals in the Blue Nile Basin imply less energy generation in Egypt. For the first two climate scenarios, the average annual reduction is 18.6% at the low demand target level and 30% at the high demand target level. For the 2050 climate, the percentages increase to 22% and 37% respectively.

- At the basin-wide scale, the total energy output in Scenario II is three to four times higher than that of Scenario I.

- Similar remarks can be made for the firm energy output (Figure 5.2.3). In fact, in percentage terms, firm energy (at the sub-basin as well as the basin-wide scales) declines faster than average energy as irrigation withdrawals increase.

- The annual average and firm energy generation of the Victoria Nile remains unchanged.

Sensitivity of River Flow to Demand and Climate Changes

The river flow basin response for Scenario II is depicted on Figure 5.2.4. As expected, the flows at Lake Albert and Malakal are identical to those of Scenario I (Figure 5.1.4). The higher upstream withdrawals, however, cause the flows at Khartoum and (consequently) Dongola to be considerably less. Comparing Figures 5.1.4 and 5.2.4 for the baseline climate, Khartoum and Dongola flows are reduced by 33% and 13% respectively at the low demand target level, and 60% and 24% respectively at the high demand target level. The percentage reductions increase for the 2050 climate.

5.3 Development Scenario III

Development Scenario III focuses on the southern Nile and includes (1) construction of major water conservation projects at the Sudd, the Machar Marshes, and the Sobat River Basin, (2) full regulation of the Equatorial Lakes, and (3) full development of the Victoria Nile hydropower potential. No development is assumed for the Blue Nile Basin. The operation of the Equatorial Lakes aims at satisfying the local objectives, and the operation of the Jonglei Canal is designed to maintain the seasonal swamp area.

Sensitivity of Water Supply Deficits to Demand and Climate Changes

Figure 5.3.1 quantifies the impact of the aforementioned projects on water supply. A comparison of this figure with Figure 5.1.1 (of Scenario I), leads to the following comments:

- Equatorial Lake regulation eliminates water supply deficits in this region for all climate scenarios and demand levels.

- Ethiopian and Sudanese water supply deficits remain the same as in Scenario I. This is because no development takes place along the Blue Nile.

- As a result of the wetland projects, Egypt's water supply deficits are reduced by a substantive margin for all climate scenarios and demand targets. More specifically, at the current demand targets, Egyptian water deficits are reduced by about 5 billion cubic meters per year for all climate scenarios. At the low demand target level, the deficit reduction exceeds 6 billion cubic meters per year, while at the high demand target level, it exceeds 7 billion cubic meters per year.

Sensitivity of Energy Generation to Demand and Climate Changes

Figures 5.3.2 and 5.3.3 quantify the annual average and firm energy benefits of the southern Nile projects:

- Victoria Nile energy output exhibits a 10-fold increase over Scenario I. For the baseline and 2020 climate scenarios, the Victoria Nile energy output approximately equals or exceeds 14,000 GWh per year, an amount equal to 50% of the total basin-wide energy generation. For the 2050 climate scenario, energy generation is somewhat less but well over 10,000 GWh per year. To a limited extent, the hydropower versus irrigation tradeoff also exists for the Equatorial Lake region. This tradeoff would intensify at higher water withdrawals.

- Blue Nile energy generation practically remains the same as in Scenario I.

- The wetland projects increase energy generation in Egypt for all climate scenarios and demand levels. The percent generation increase over Scenario I ranges from 25% to 35%.

- At the basin-wide scale, the total energy output of Scenario III is higher (more than twice) than the output of Scenario I, but less than the output of Scenario II.

- The southern Nile projects have a substantive impact on firm energy generation (Figure 5.3.3). Due to the vast Equatorial Lake storage, the firm energy of the Victoria Nile is 90% of the average annual generation. Furthermore, the wetland projects increase firm energy generation in Egypt by 50% to 200% (relative to Scenario I), and raise the total basin-wide firm energy higher than both previous scenarios.

Sensitivity of River Flow to Demand and Climate Changes

Scenario III river flows are depicted on Figure 5.3.4. To avoid wetland flooding, Lake Albert releases about half a billion cubic meters per year less than Scenario I—Figure 5.1.4. The most significant effect, however, is the flow augmentation at Malakal of about 12.5 to 13.5 billion cubic meters per year. This effect carries over to Dongola the flow of which also increases for the first two climate scenarios by 11.5 to 12.5 billion cubic meters per year. For the 2050 climate scenario, the wetland benefit at Dongola ranges from 8.5 to 10.5 billion cubic meters per year.

5.4 Development Scenario IV

Scenarios II and III evaluated the impacts of water development projects in the two major Nile sub-basins, the eastern (Blue) Nile and the southern (White) Nile, assuming that development does not occur concurrently. Development Scenario IV assumes concurrent development in the two regions. Furthermore, it implements a strategy of basin-wide cooperation in which all storage projects (regardless of their location) are operated to mitigate the adverse impacts of water shortages anywhere in the basin.

Sensitivity of Water Supply Deficits to Demand and Climate Changes

Figure 5.4.1 quantifies the impact of Scenario IV on water supply. A comparison of this figure with Figures 5.1.1 (Scenario I), 5.2.1 (Scenario II), and 5.3.1 (Scenario III), supports the following conclusions:

- More than any other scenario, basin-wide development and cooperation minimizes (nearly eliminating) water supply deficits for the Equatorial Lake region, Ethiopia, and Sudan for all climate scenarios and demand targets. The same applies for Egypt at the current demand target level. At the low demand target level, Egypt's deficits are somewhat higher than those of Scenario III (southern Nile development only), but considerably less than those of Scenarios I and II. The difference between Scenarios IV and III is 1.3, 1.6, and 4.1 billion cubic meters per year respectively for the baseline, 2020, and 2050 climate scenarios. However, if the deficits of Egypt *and* Sudan are combined, Scenario IV becomes most favorable, and Egypt and Sudan increase their current share (baseline conditions—Scenario I). The same conclusion applies at the high demand targets where Scenario IV exhibits the least *basin-wide* deficit. Since the country shares were determined somewhat arbitrarily, these results indicate that cooperative basin development and management could entail benefits for all.

Sensitivity of Energy Generation to Demand and Climate Changes

Figures 5.4.2 and 5.4.3 quantify the annual average and firm energy benefits of the basin-wide development and cooperation scenario:

- Basin-wide average energy generation (Figure 5.4.2) is highest under Scenario IV. Compared to Scenario I, energy output increases by approximately 40,000

GWh per year, a factor of five. Energy generation also has a favorable *sub-basin* distribution. For the Victoria Nile, Scenario IV energy generation is optimal. For Ethiopia/Sudan, Scenario IV energy generation is within 5% of the most favorable case (Scenario II), while for Egypt, it is second best after Scenario III. At the basin-wide scale, the tradeoff between hydropower and irrigation approximately implies a 15% energy loss at each higher demand target level. Climate change (from the baseline to the 2050 scenario) is expected to reduce energy generation by 10% to 12%.

- The same comments apply to firm energy generation (Figure 5.4.3) both at the basin-wide as well as the sub-basin scales. Basin-wide firm energy experiences a 13% reduction at each new demand target level, and declines by 15% to 25% as a result of climate change.

Sensitivity of River Flow to Demand and Climate Changes

Scenario IV river flows are depicted on Figure 5.4.4. Comparing Scenarios I (Figure 5.1.4) and IV, the flow conditions at Albert and Dongola are similar. In fact, the Scenario IV Dongola flow at the low demand targets is comparable to the Scenario I flow at current conditions. Due to the extensive water withdrawals in the Blue Nile basin, the Scenario IV Khartoum flow is less than that of Scenario I at high demand targets. However, the wetland water augmentation projects increase the flow at Malakal, and the net result downstream of Khartoum is a flow similar to the baseline. Thus, the water allocation concept of Scenario IV is to use the White Nile water augmentation projects to meet the water demands in the Blue Nile basin without adversely impacting Sudan and Egypt.

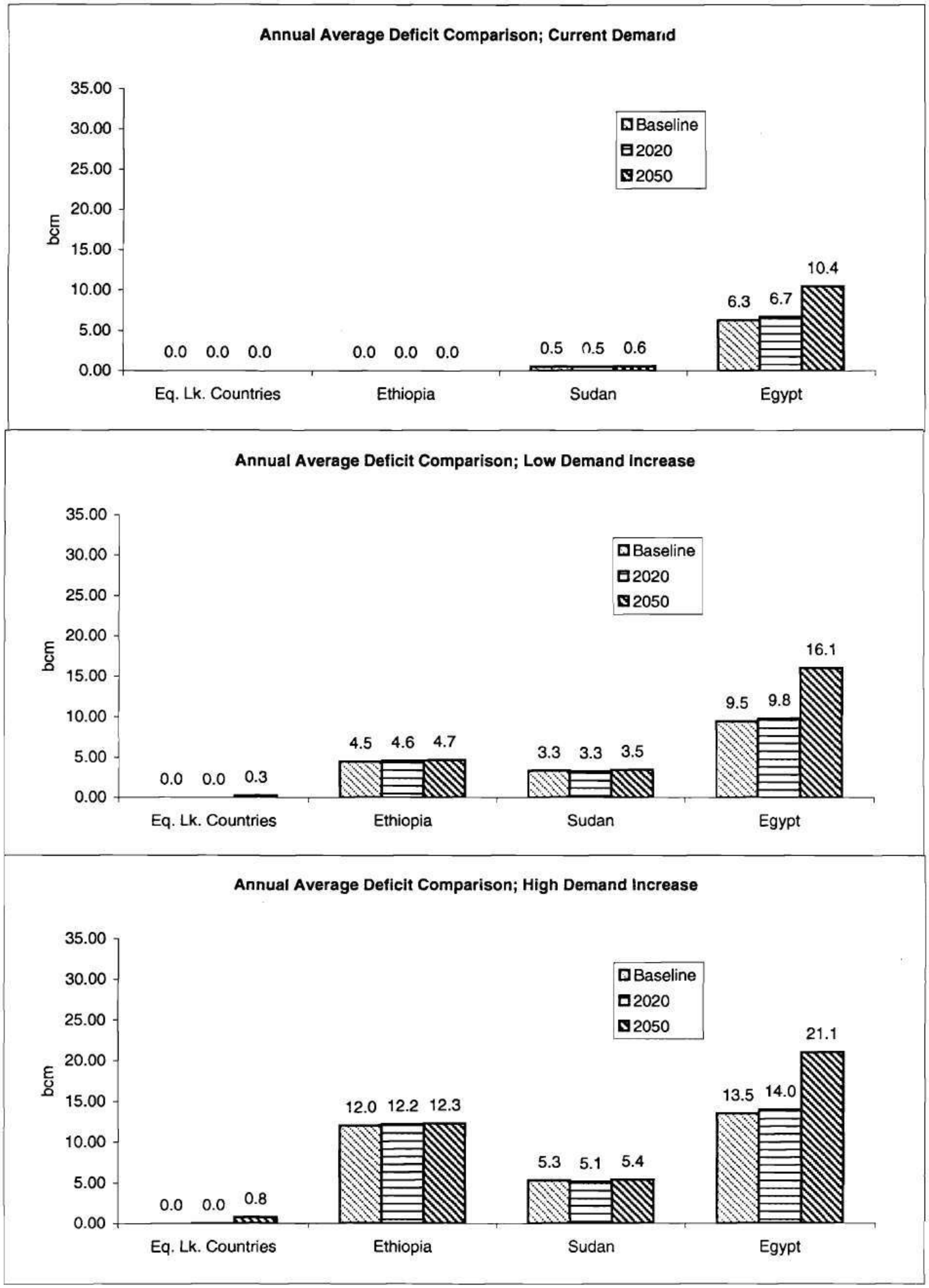


Figure 5.1.1: Annual Deficit Comparison; Scenario I

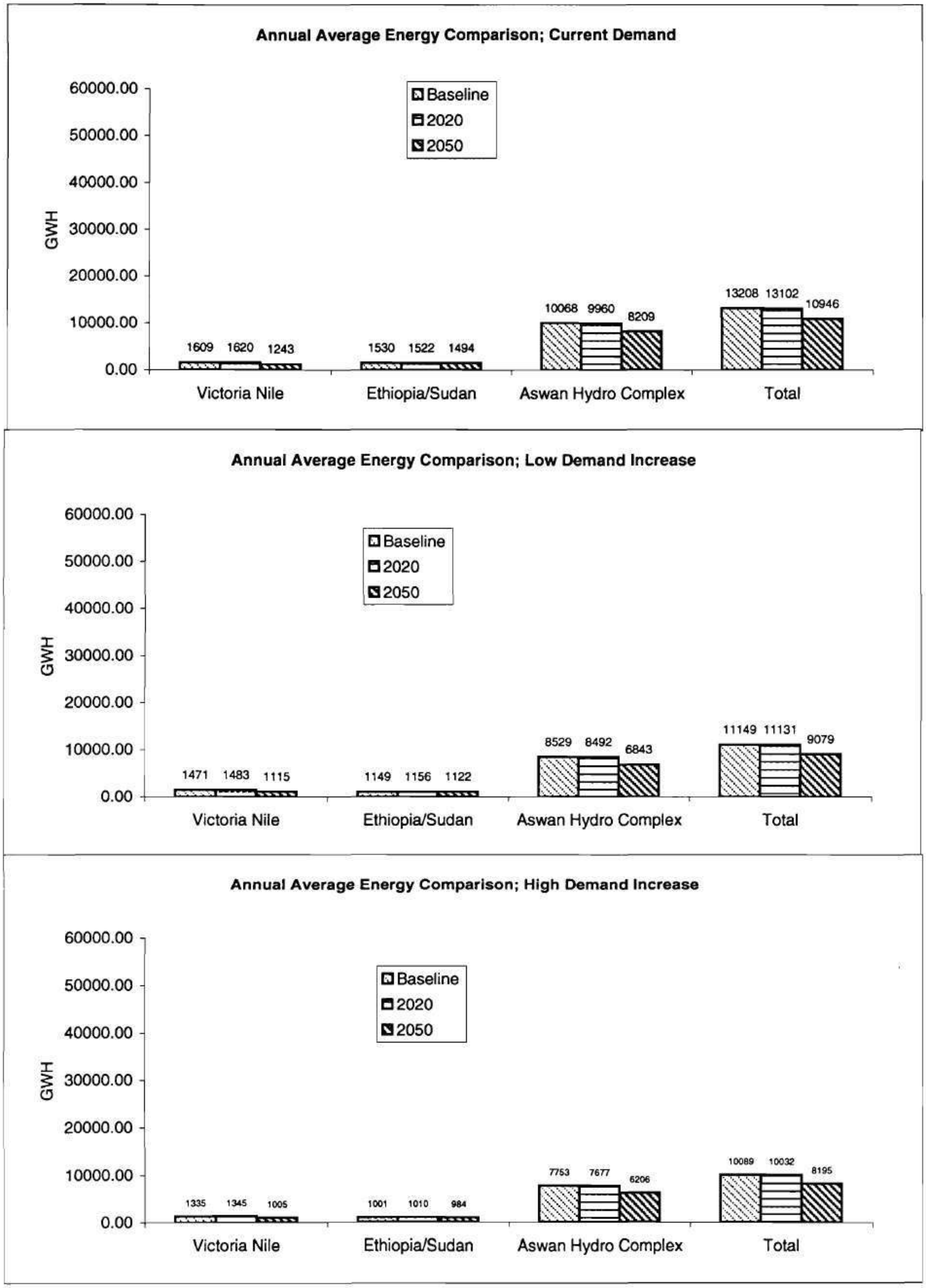


Figure 5.1.2: Annual Energy Comparison; Scenario I

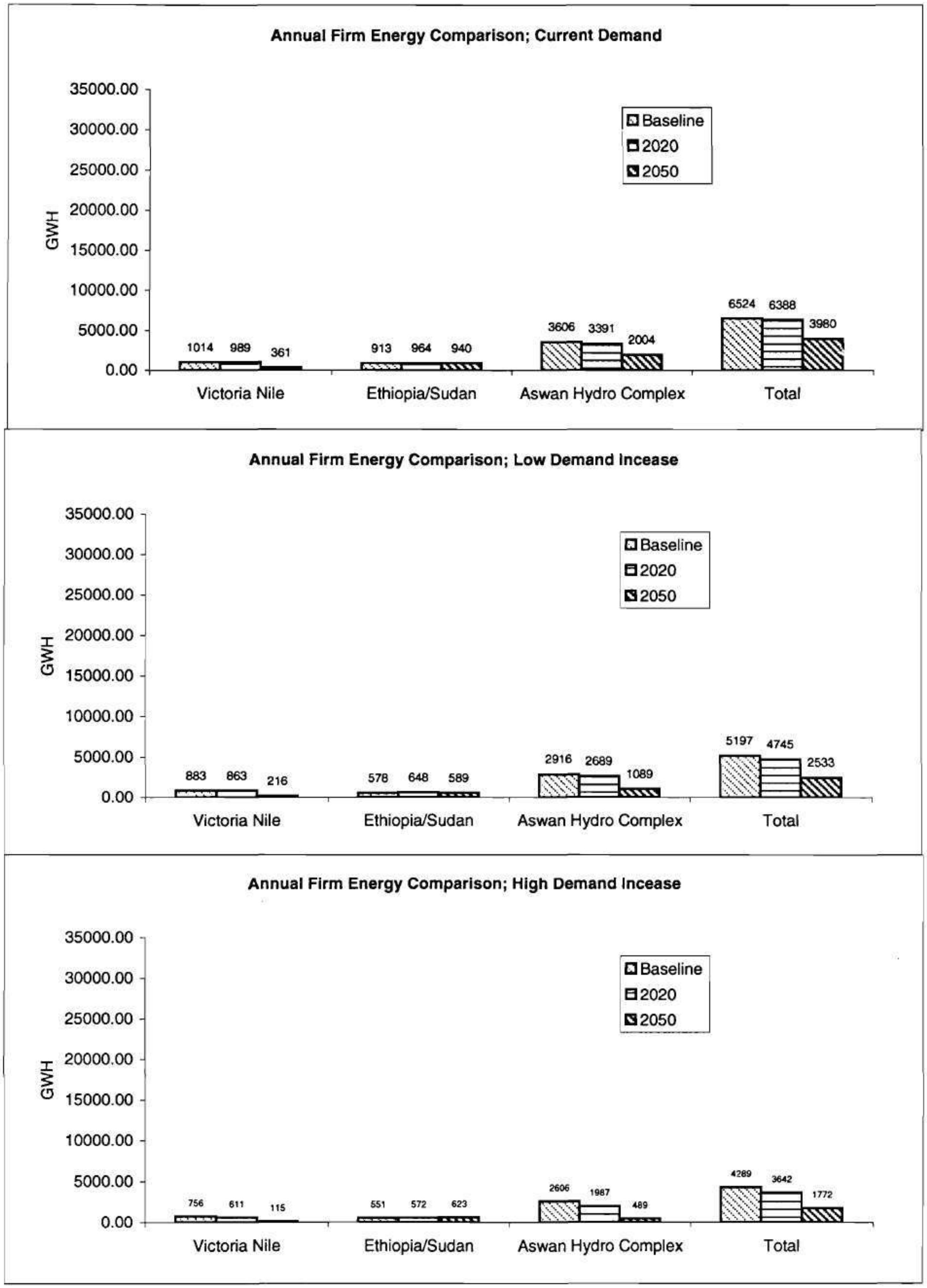


Figure 5.1.3: Annual Firm Energy Comparison; Scenario I

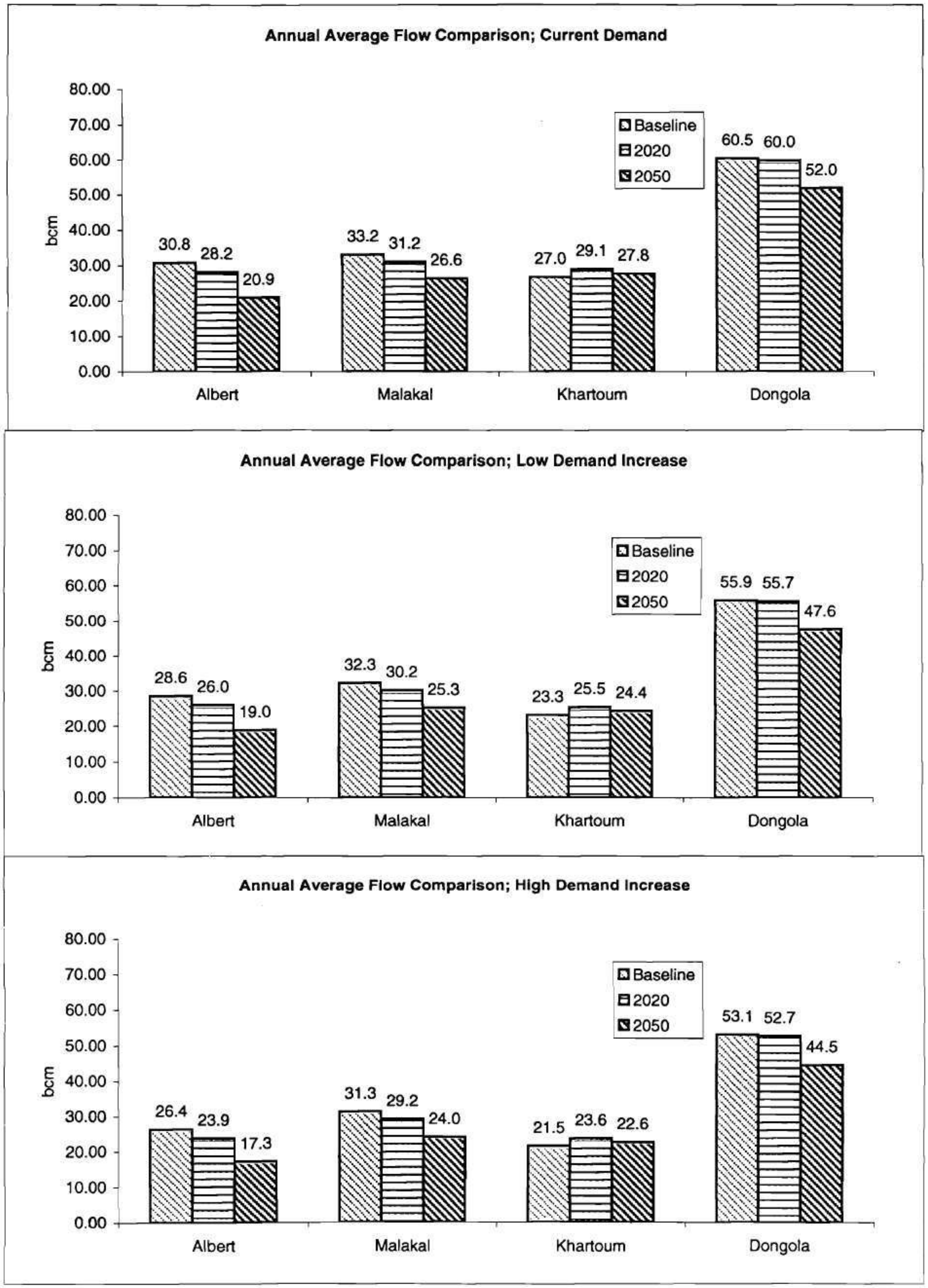


Figure 5.1.4: Annual Flow Comparison; Scenario I

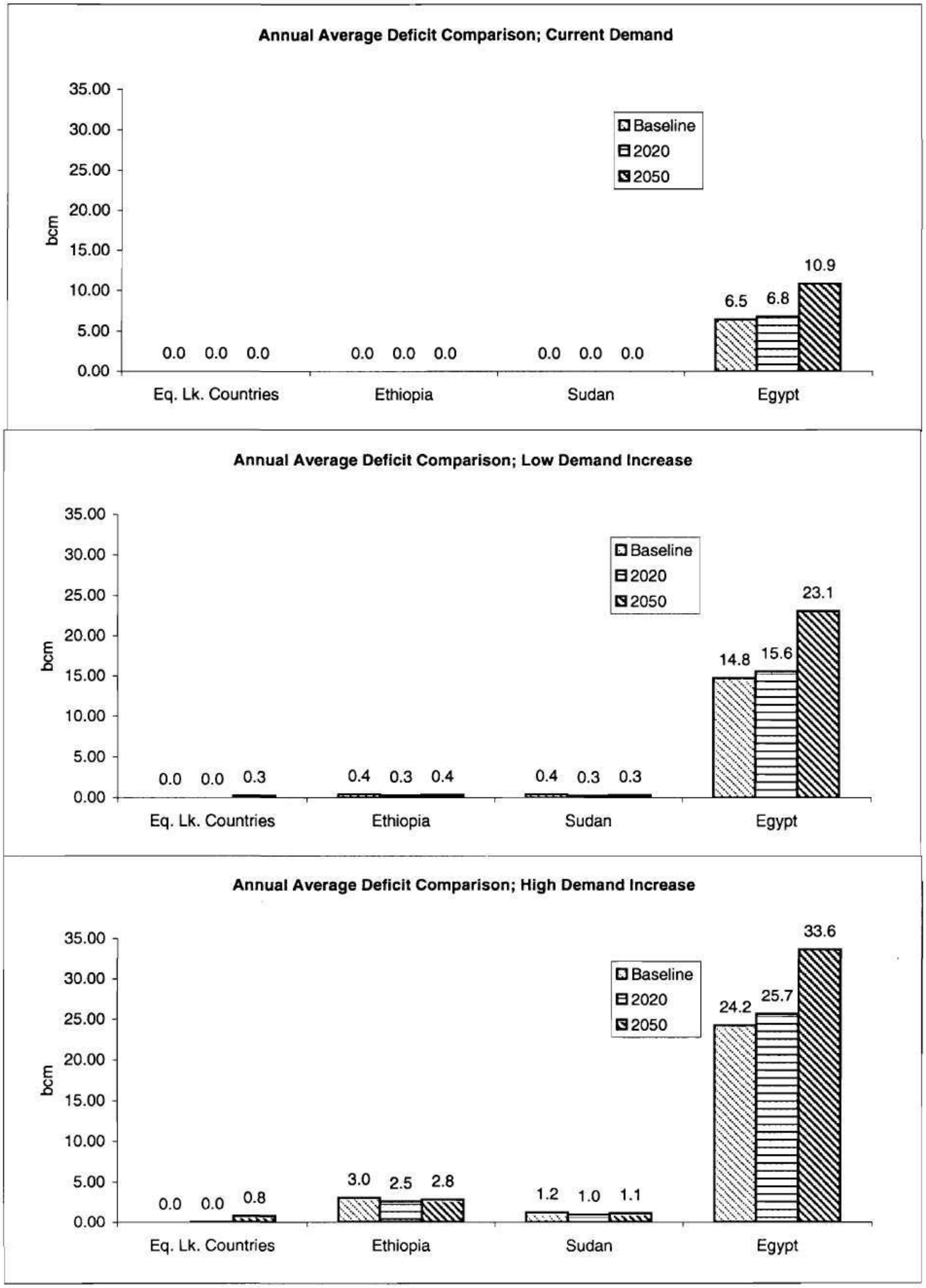


Figure 5.2.1: Annual Deficit Comparison; Scenario II

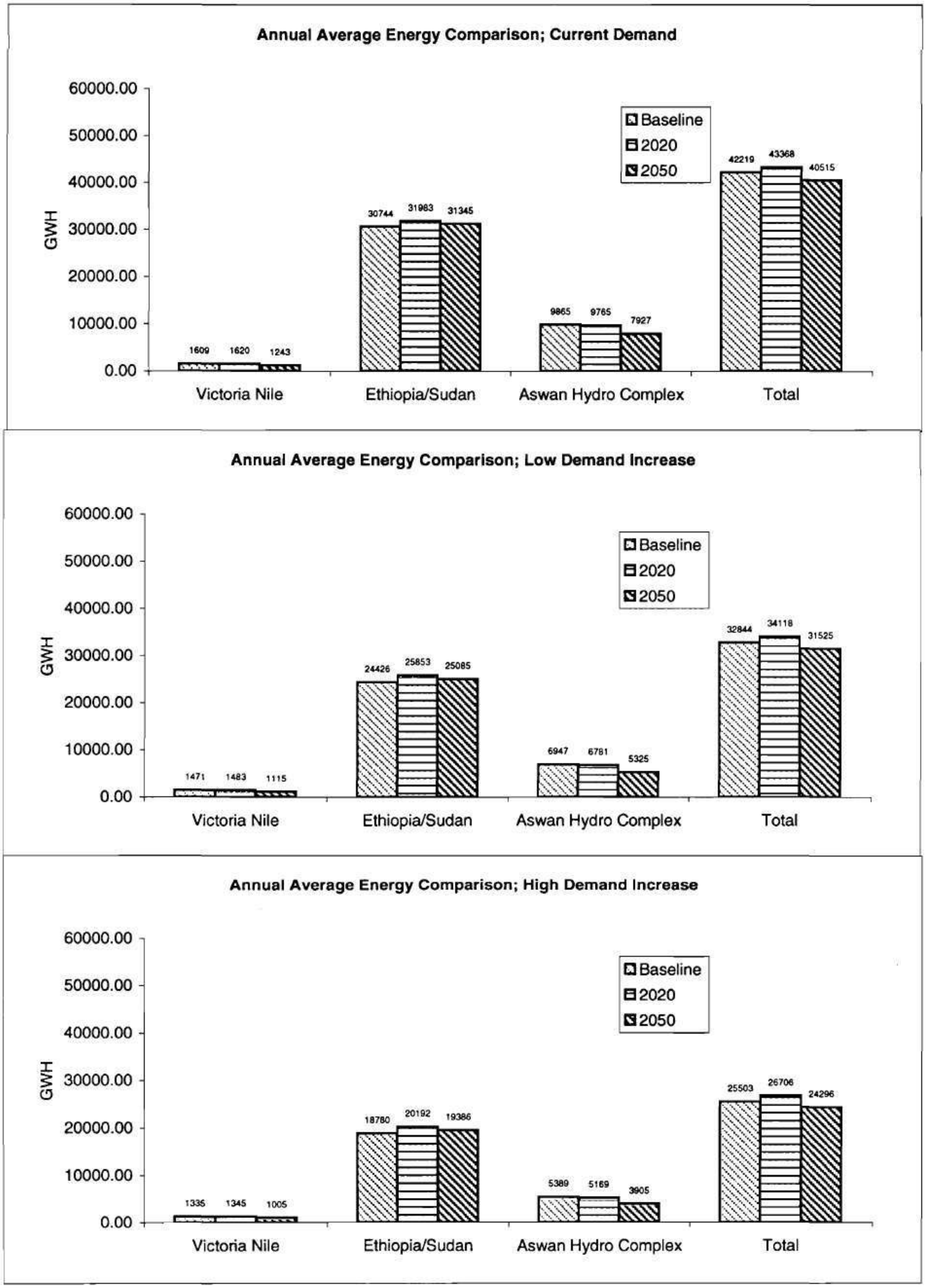


Figure 5.2.2: Annual Energy Comparison; Scenario II

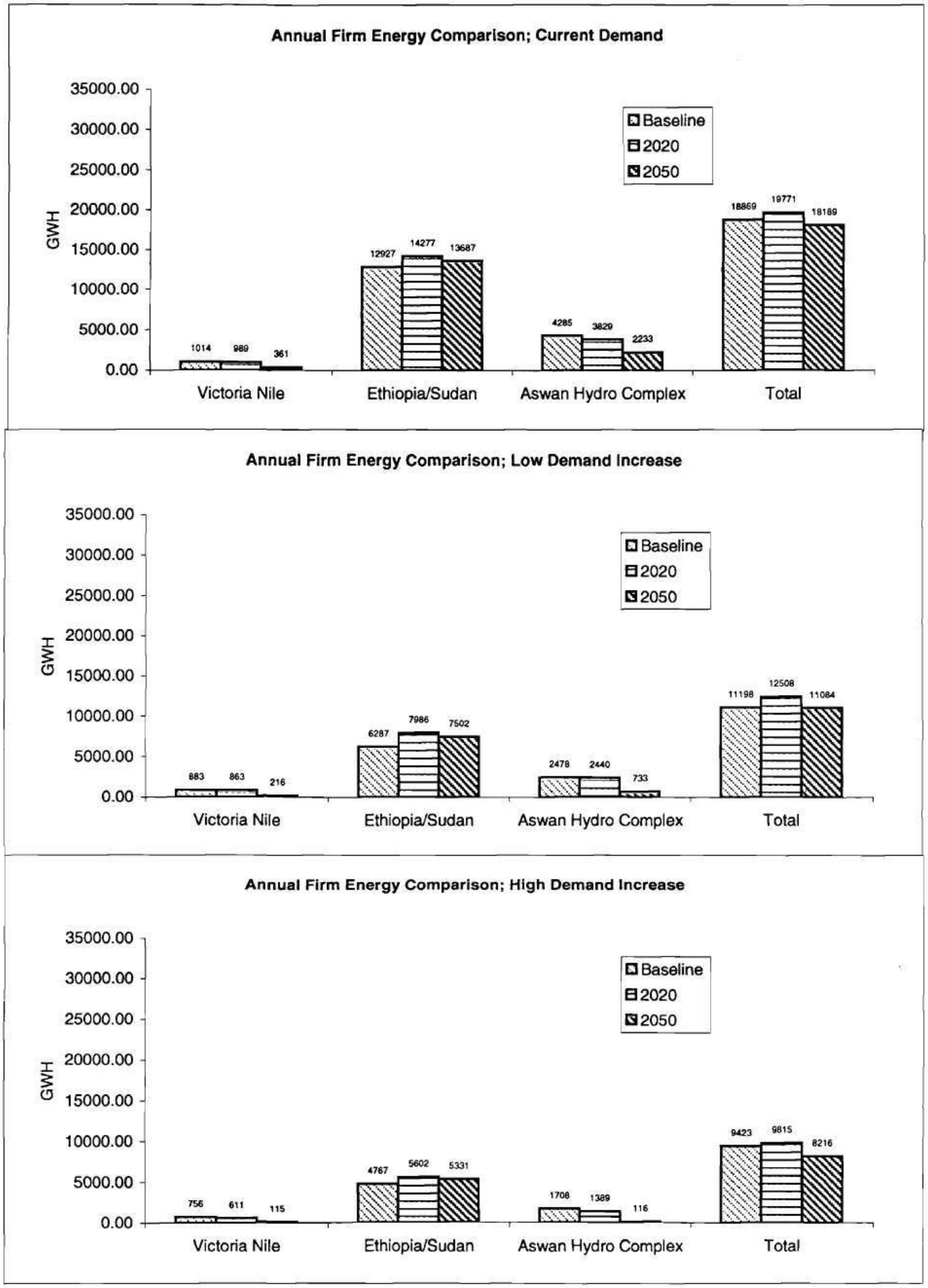
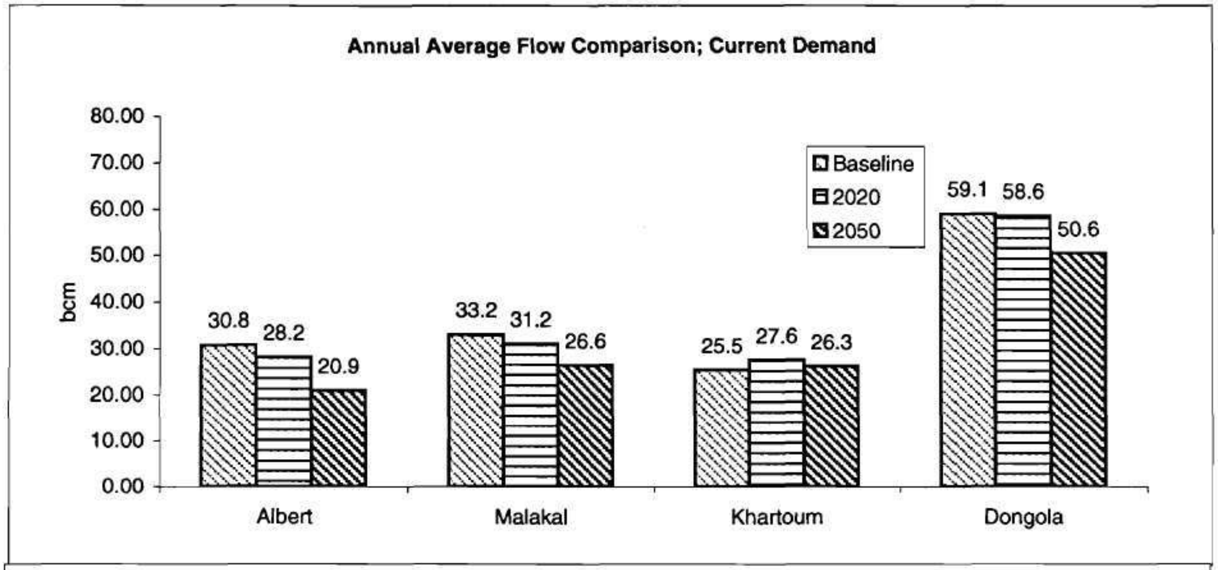
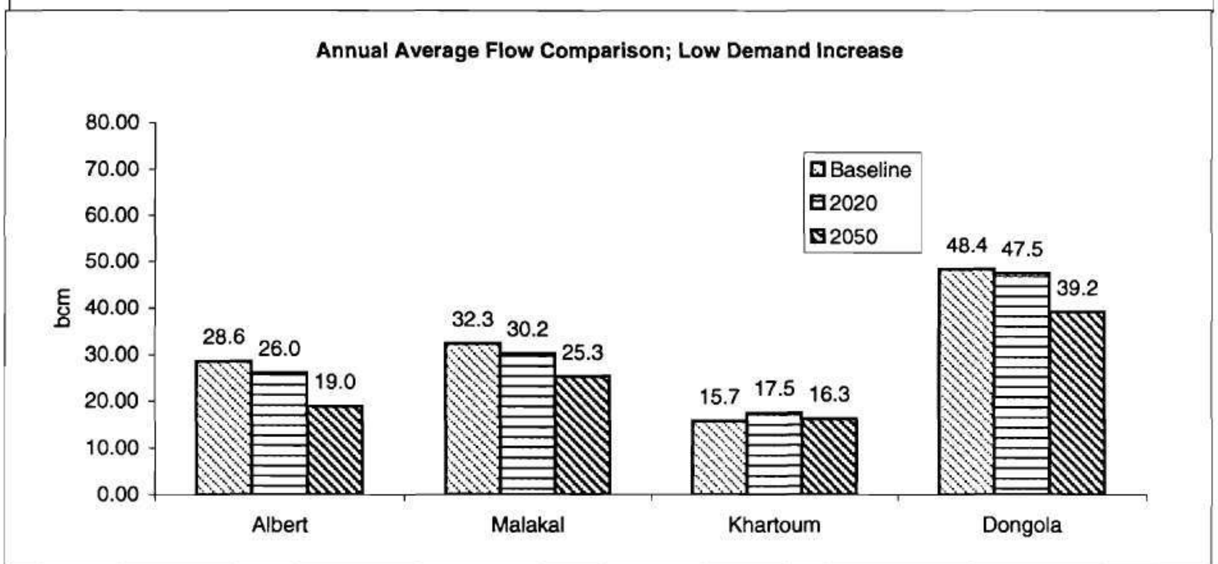


Figure 5.2.3: Annual Firm Energy Comparison; Scenario II





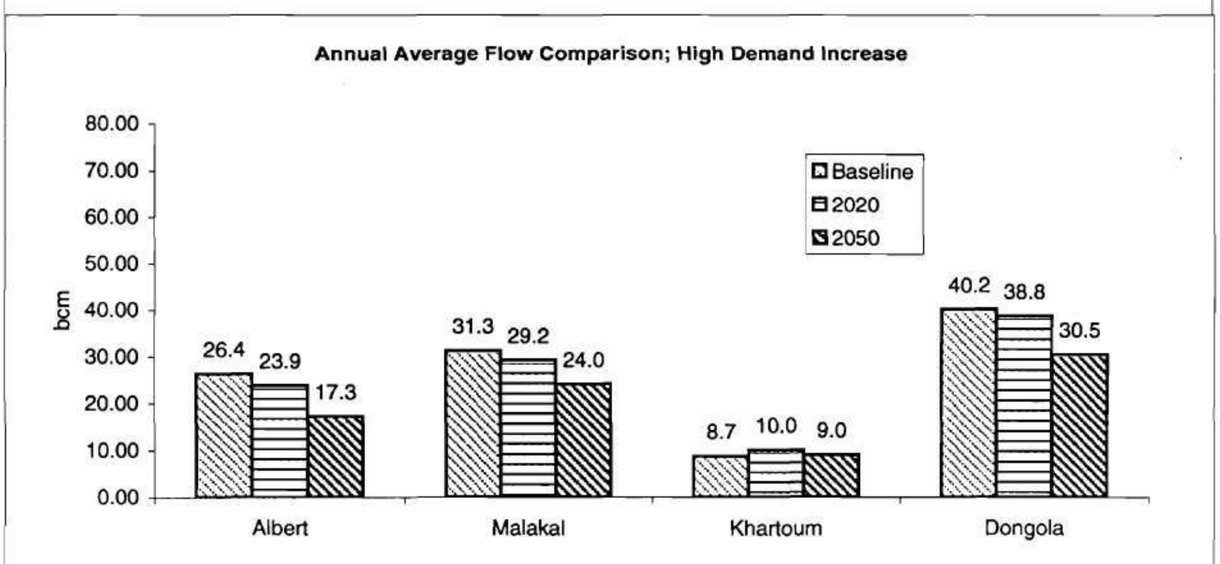


Figure 5.2.4:Annual Flow Comparison; Scenario II

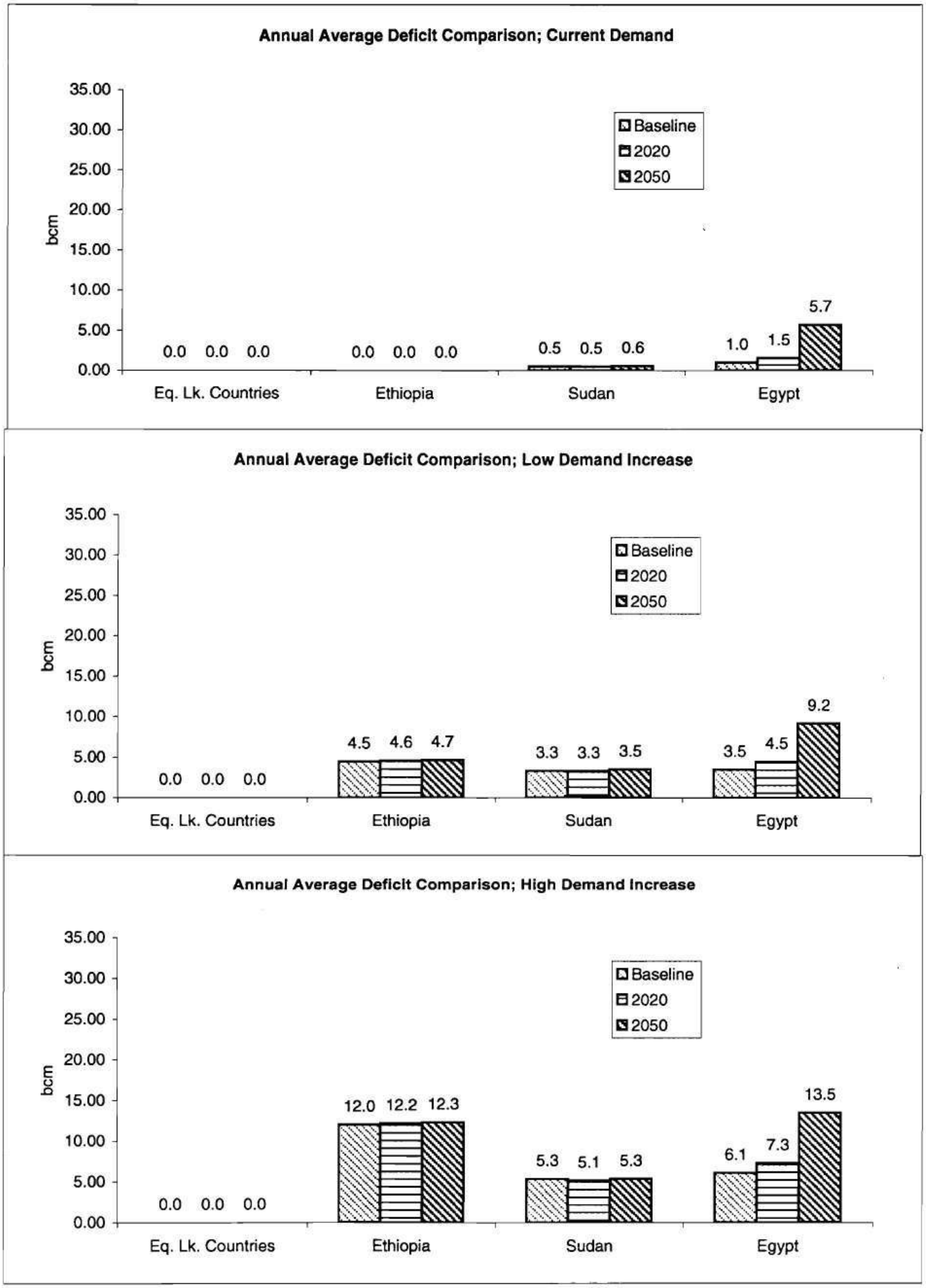


Figure 5.3.1: Annual Deficit Comparison; Scenario III

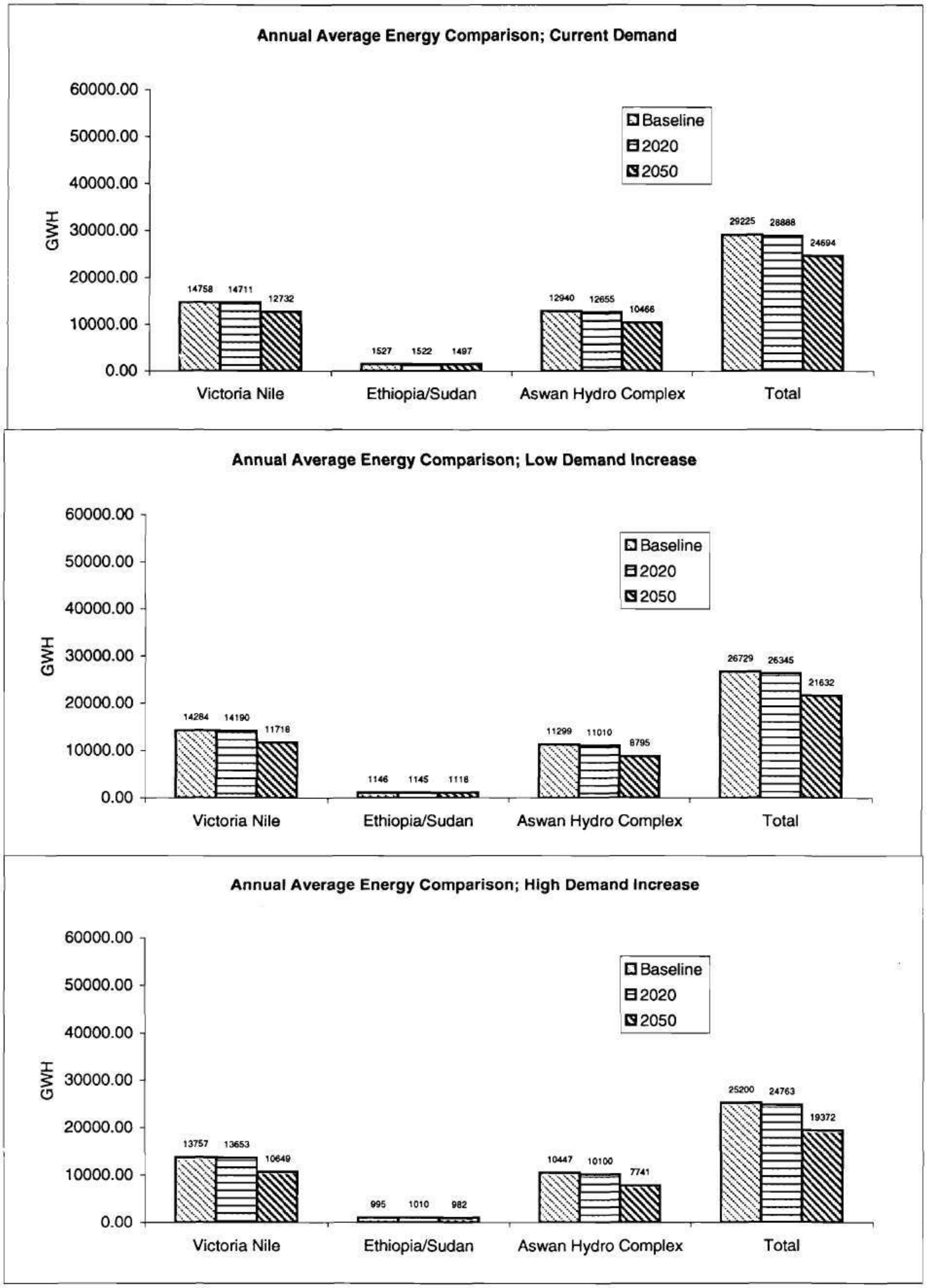


Figure 5.3.2: Annual Energy Comparison; Scenario III

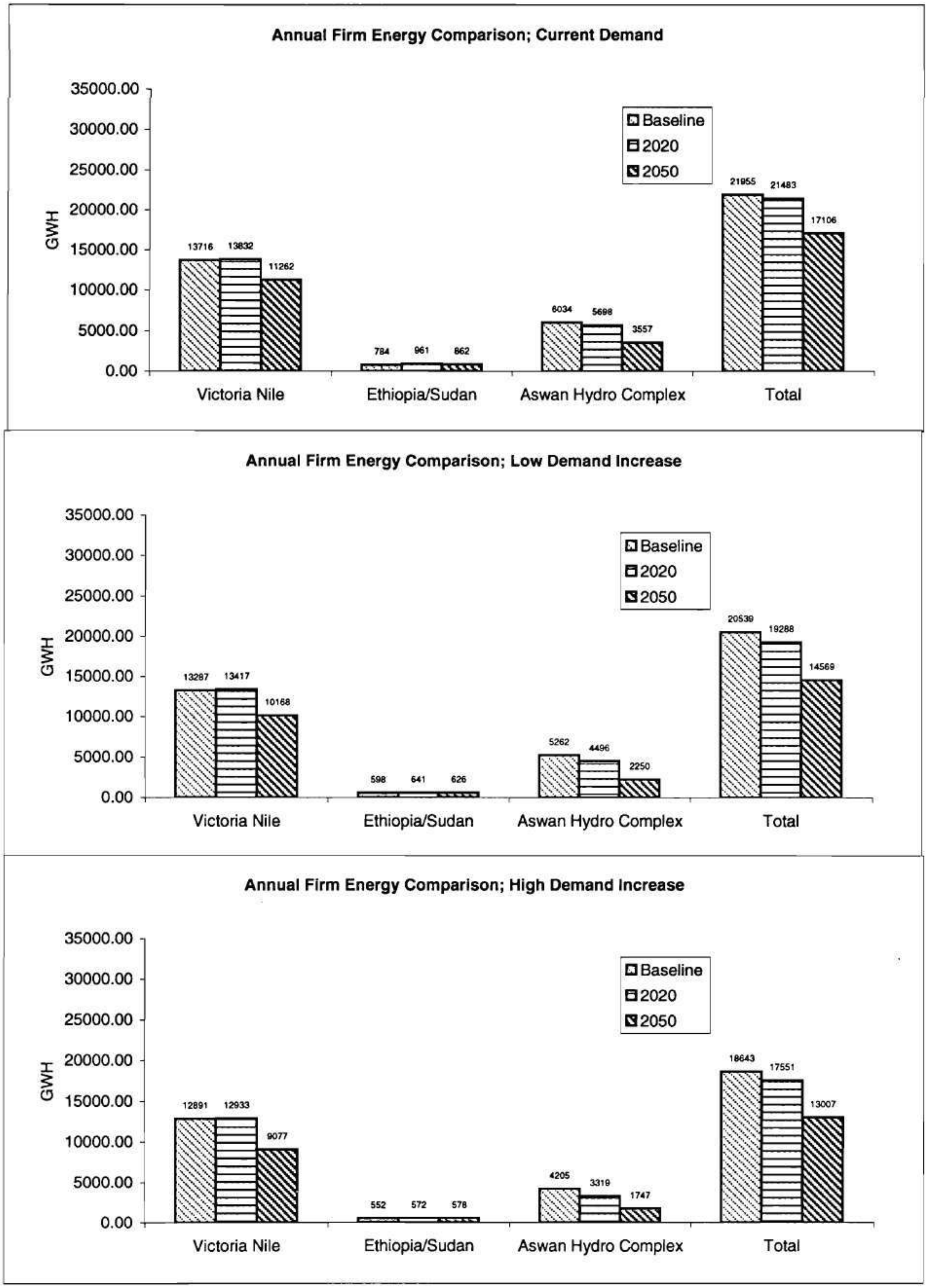


Figure 5.3.3: Annual Firm Energy Comparison; Scenario III

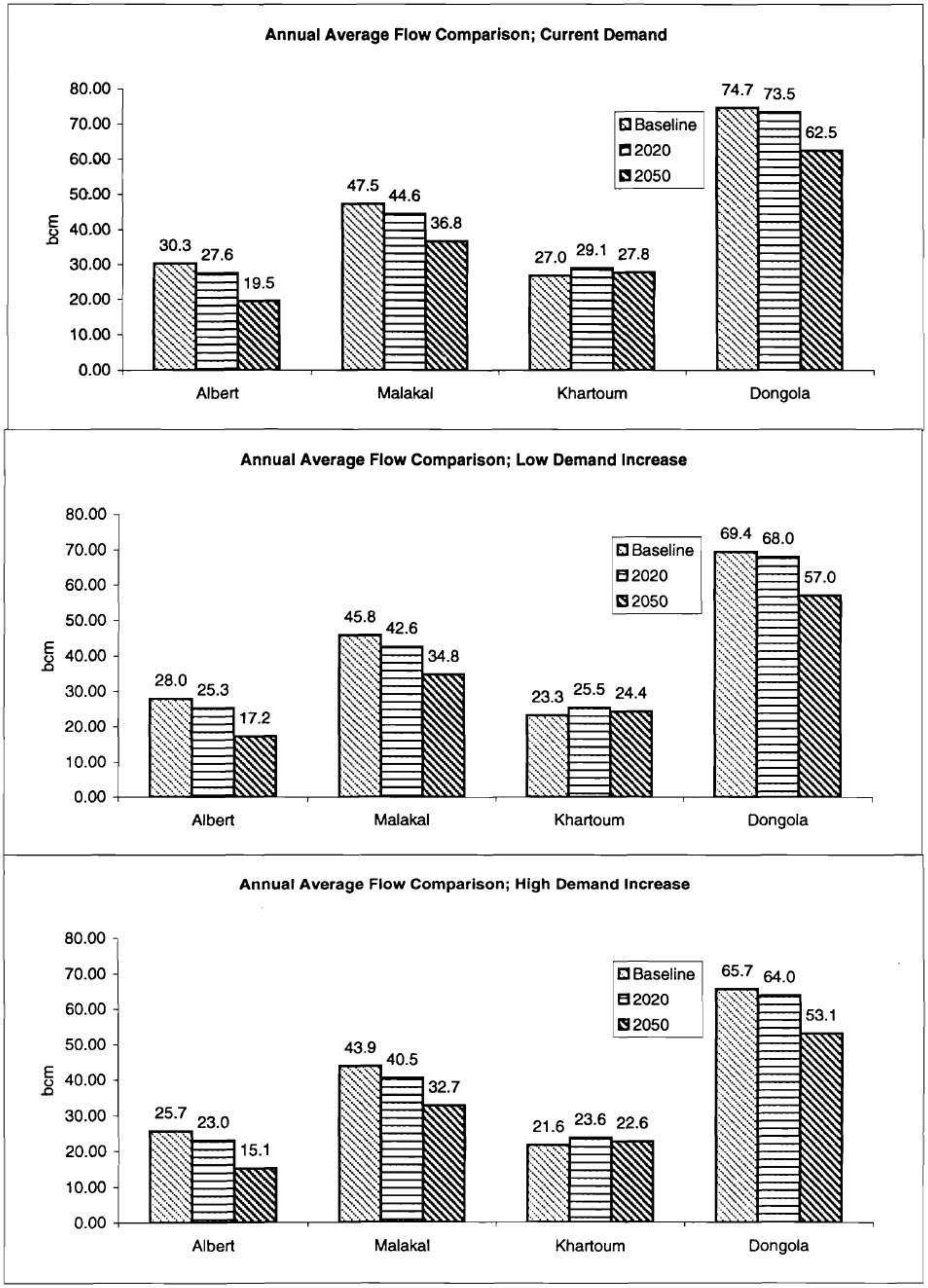


Figure 5.3.4: Annual Flow Comparison; Scenario III

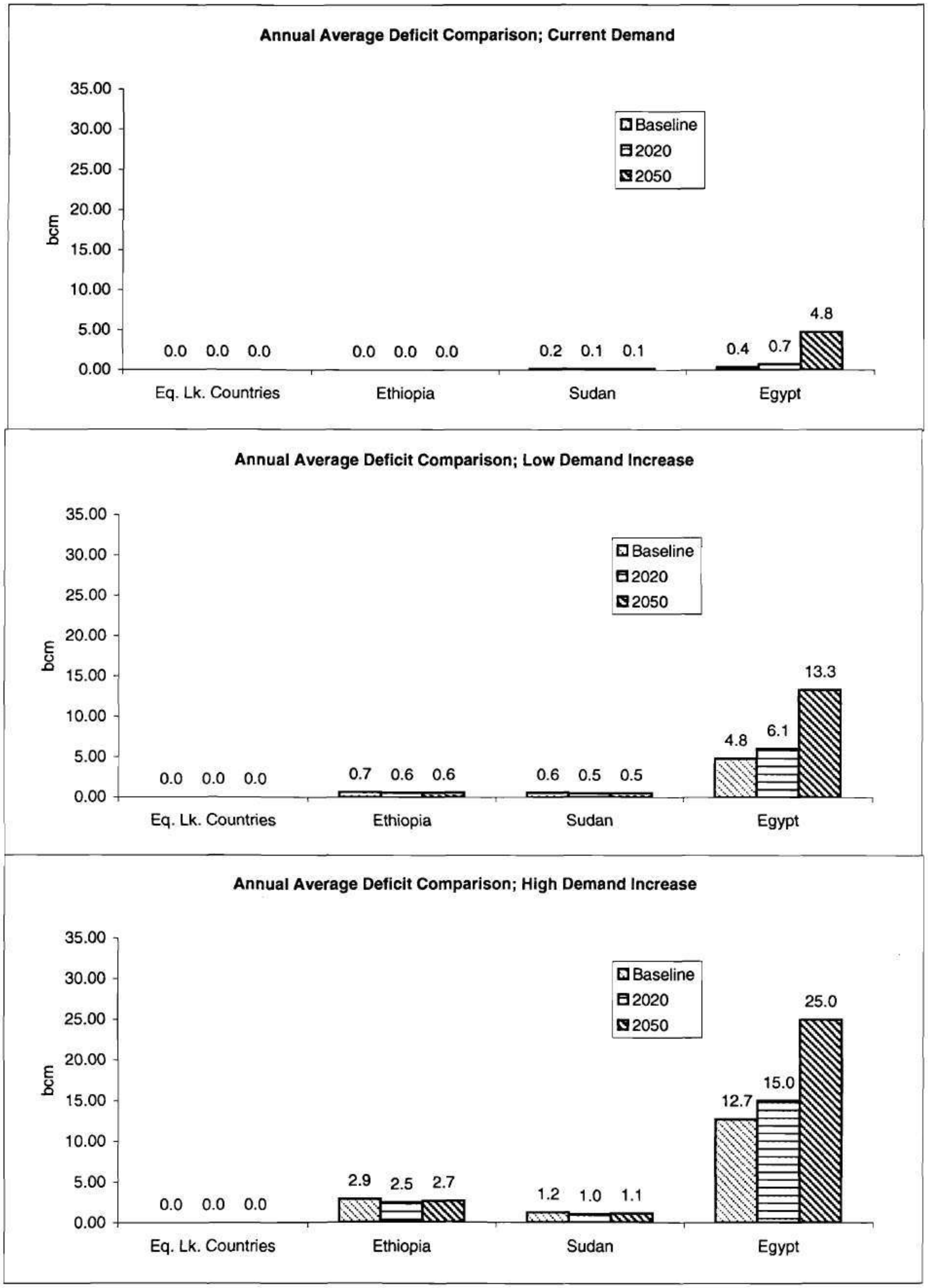


Figure 5.4.1: Annual Deficit Comparison; Scenario IV

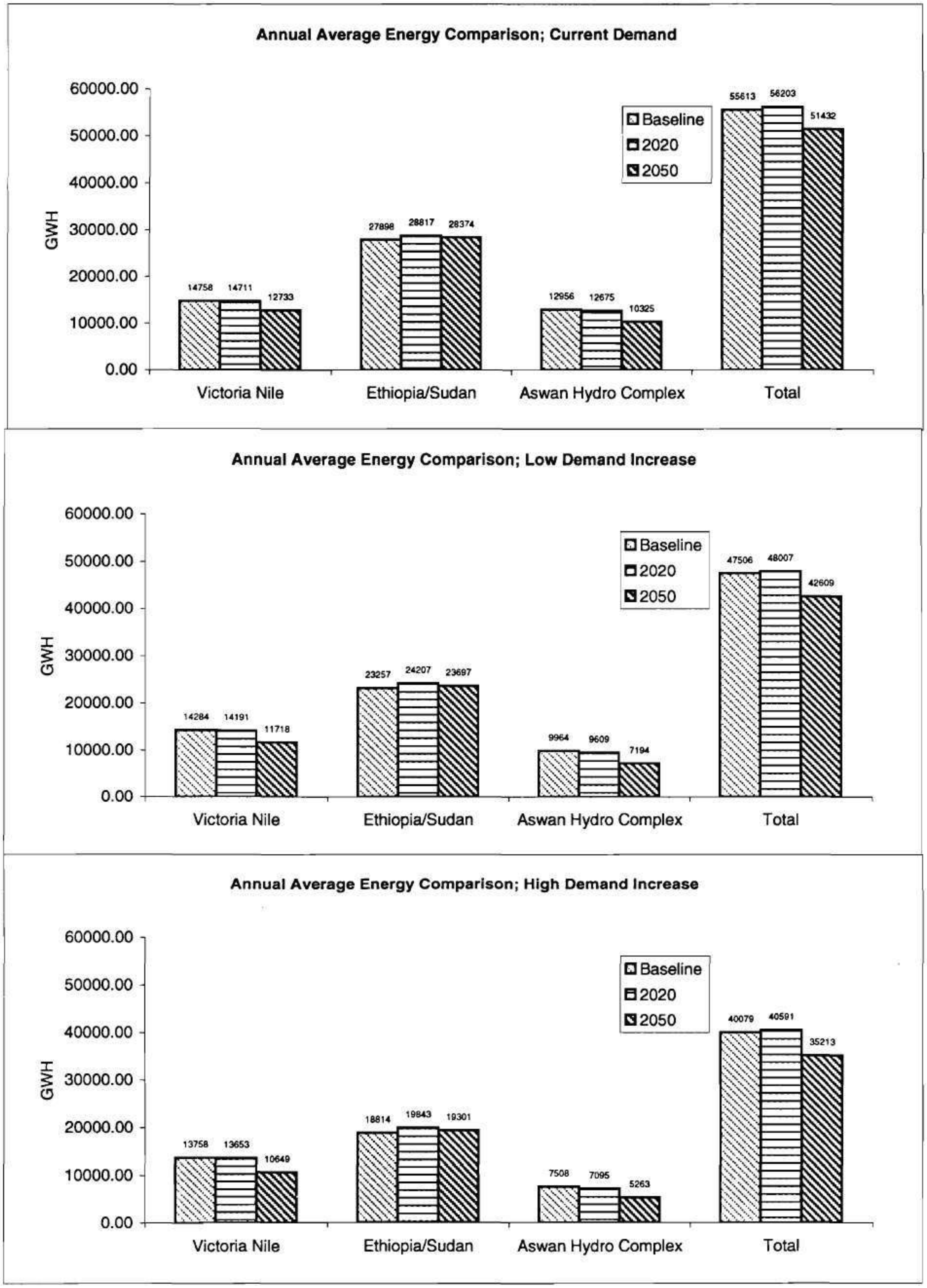


Figure 5.4.2: Annual Energy Comparison; Scenario IV

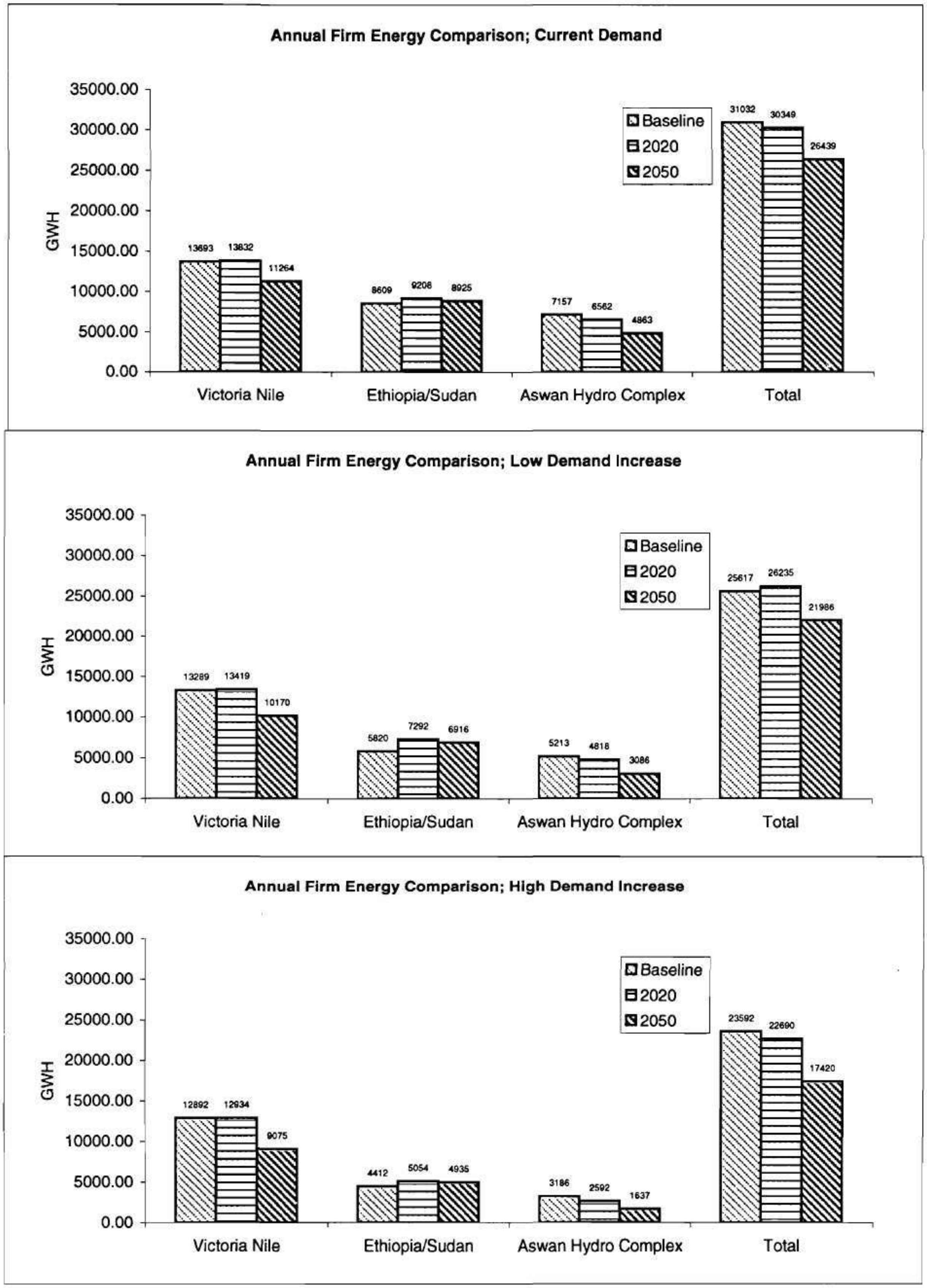


Figure 5.4.3: Annual Firm Energy Comparison; Scenario IV

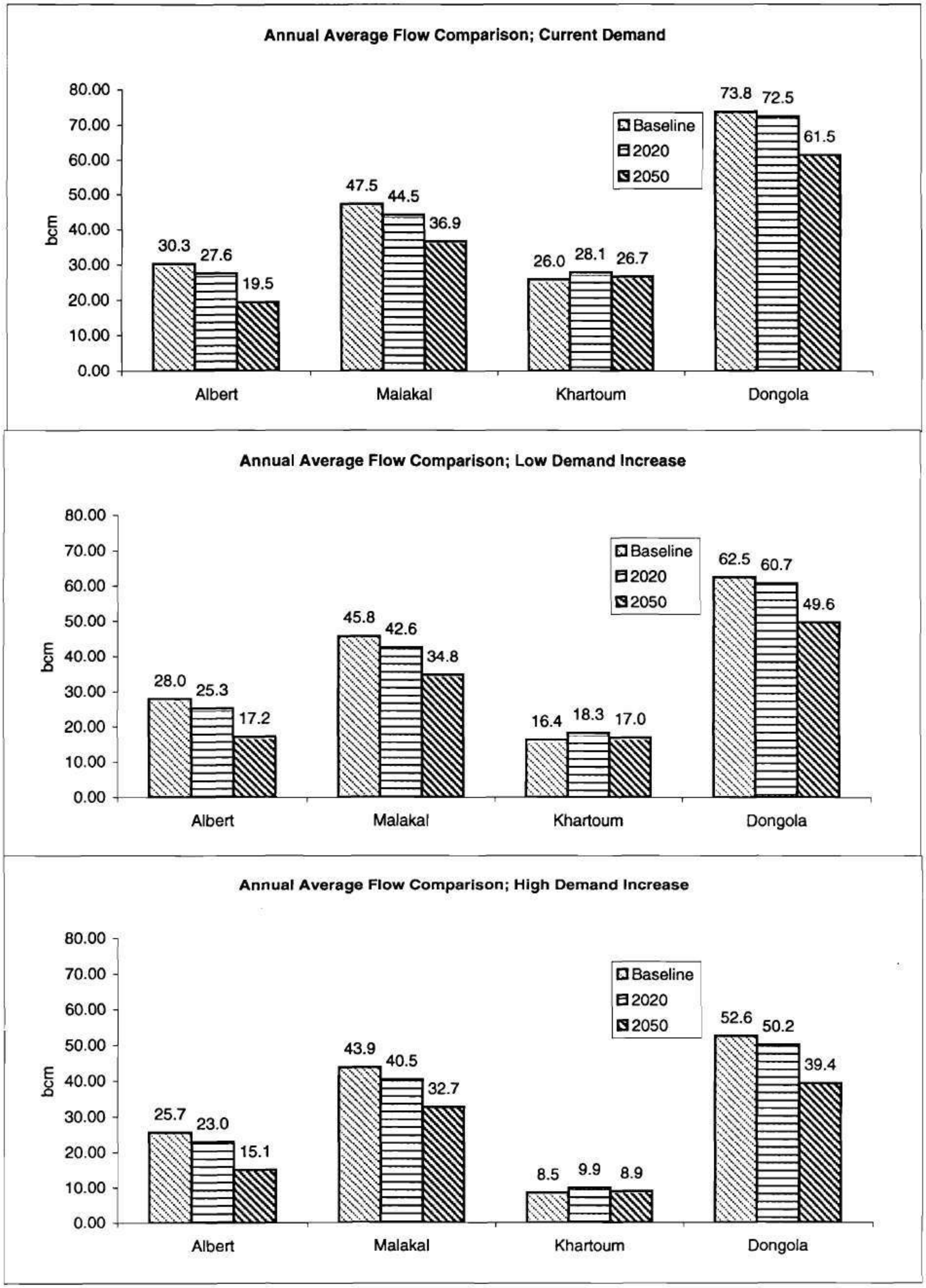


Figure 5.4.4: Annual Flow Comparison; Scenario IV

6. Conclusion

A comprehensive modeling and management system (Nile-DSS) was used to assess the benefits and impacts of 36 water development, water use, and climate scenarios for the Nile Basin. In Section 5, the results of the assessment were discussed relative to water deficits, energy generation, and river flow patterns. In this section, the discussion focuses on sub-basin projects, summarizing their main regional and basin-wide implications.

Southern Nile

The development options assessed for the Equatorial Lake region were (a) irrigated agricultural expansion, (b) hydropower development along the Victoria and Kyoga Niles, (c) lake regulation, and (d) water conservation through wetland projects. Agricultural water use could potentially increase to 5 billion cubic meters (bcm) per year within the lake basins. The lakes can reliably support this rate of consumptive water use, even for the most adverse (2050) climate scenario. However, lake regulation would be necessary to ensure water supply reliability. Hydropower development along the Victoria and Kyoga Niles would greatly enhance energy generation for the region. At full development and regulation, energy generation could reach 14,000 GWH per year, 90% of which could be guaranteed all of the time (firm energy). At the high consumptive use level (of 5 bcm per year) and for the driest climate scenario, energy generation would drop to about 10,000 GWh per year, which is still a very significant energy output.

Further downstream, lake regulation would benefit the Sudd by creating dependable seasonal wetland areas for cattle grazing during the dry months of the year. Moreover, lake storage could help mitigate droughts basin-wide. The value of drought storage, however, would be limited without the Jonglei Canal and a basin-wide management plan.

The wetlands of the Sudd, the Bahr el Ghazal, and the Sobat provide opportunities for augmenting the Nile yield, but they are also vital for the local population and ecosystems. The assessment shows that the Jonglei Canal could serve both local and basin-wide interests, but this would require that canal operation be closely coordinated with the regulation of the Equatorial Lakes. In addition to providing irrigation water (up to 2 bcm per year), the management policies could selectively regulate permanent and seasonal wetlands and reduce the adverse impacts of wet and dry years.

Assuming (based on past studies) that the wetlands of the Bahr el Ghazal and Sobat River Basins can yield a combined average of 4.75 bcm per year, the assessment shows that substantial irrigation and energy generation benefits would accrue to the downstream users.

Eastern Nile

The Blue Nile Basin offers exciting opportunities for hydropower development, irrigated agricultural expansion, and flow regulation. The combined energy generation potential of the proposed and existing hydropower facilities in Ethiopia and Sudan is on the order of 33,000 GWH per year, almost three times higher than the current energy generation in the entire Nile Basin. Most of this generation, approximately 31,000 GWh, would occur in Ethiopia. Increased irrigation of up to 20 bcm per year in Ethiopia and 5 bcm in Sudan could also be dependably sustained, provided that full hydropower development takes place in Ethiopia creating more than 60 bcm of combined reservoir storage. However, irrigation withdrawals upstream of the hydropower facilities would reduce Ethiopian generation. The rate of reduction would be about 500 GWh per year for every billion cubic meter dedicated to irrigation. The climate scenarios indicate that the Blue Nile Basin is not expected to experience any major climate change. However, it should be noted that climate model uncertainty is significant, and it would be appropriate to view this as an exercise in sensitivity analysis.

Main Nile

The dominant water uses of the Main Nile are Egyptian irrigation and hydropower. The investigation focused on assessing the feasibility of increasing Egyptian water use by 2.5

and 5 bcm over the current rate of 55.5 bcm per year. These increases are considered simultaneously with upstream irrigation withdrawals, with the latter occurring first. While all cases show water deficits relative to increased demand targets, at the low demand target level, Egypt could increase its current water use. This, however, would require implementation of the full cooperation scenario. By contrast, a position of no cooperation would necessitate that Egypt decrease its current water use by a significant margin. Combining the Egyptian and Sudanese shares would accrue some benefits to both countries (over and above current consumption) even at the high demand target level. However, while this would hold for the first two climate scenarios, the third climate scenario (2050) would lead to significant average deficits relative to current water use. With the exception of Scenario IV, if upstream consumptive water use increases significantly, High Aswan Dam levels would experience severe drawdowns and energy generation would decline sharply.

Basin-wide Cooperation

The assessment demonstrates that cooperative water development and management at the sub-basin and basin levels evoke benefits for all Nile Basin nations. The basin offers exciting water development opportunities and markets for water products. Consider hydropower. With the possible exception of environmental impacts, hydropower development projects (along the Victoria and Kyoga Niles in Uganda and the Blue Nile in Ethiopia) would accrue benefits to local as well as to upstream and downstream riparians and would provide strong incentives for economic cooperation. In this regard, energy generation in Uganda could be marketed to Kenya, Tanzania, southern Sudan, and possibly other countries in the region, enabling industrial growth and economic development. Energy generation in Ethiopia could likewise benefit Sudan, Eritrea, and Egypt. Furthermore, if coordinated across national boundaries, hydropower project storage could mitigate floods and droughts basin-wide. This would require the use of shared data monitoring and acquisition systems, effective modeling tools, and a basin-wide water management process in which all major basin stakeholders are fully represented.

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Appendix A

Development Project Features

Table A.1: Recorded Minimum, Mean, and Maximum Lake Levels, Storage Volumes, and Outflows

		Victoria [1900 – 1977]	Kyoga [1912 – 1977]	Albert [1905 – 1977]
Minimum	Level (m)	1133.08	1030.31	618.75
	Storage (10^9 m^3)	2905.73	5.44	145.88
	Outflow (10^9 m^3/yr.)	10.94	8.83	10.82
Mean	Level (m)	1134.28	1031.81	620.51
	Storage (10^9 m^3)	2985.65	10.49	155.20
	Outflow (10^9 m^3/yr.)	25.48	24.82	28.38
Maximum	Level (m)	1136.28	1034.11	623.97
	Storage (10^9 m^3)	3121.32	20.35	175.68
	Outflow (10^9 m^3/yr.)	55.22	62.78	64.64

Table A.2: Existing and Potential Energy Generation Sites on Victoria and Kyoga Niles

	Hydroelectric Site	Power Capacity (MW)
Victoria Nile	Owen Falls	380
	Bujagali	320
	Kalagala	450
Kyoga Nile	Kamdini	180
	Ayago	538
	Murchison Falls	416

Table A.3: Existing and Potential Reservoirs on the Blue Nile and the Atbara Rivers

	Lake Tana	Karadobi	Mabil	Mendaia	Border	Roseires	Sennar	Khashm El Girba
Max. Level (m)	1787.57	1156.00	910.60	743.60	575.00	481	421.7	473
Max. Storage (bcm)	13.84	34.20	14.11	16.72	10.75	2.72	1.07	1.35
Min Level (m)	1783.80	1041.00	837.80	724.81	563.43	467	415	450
Min. Storage (bcm)	2.34	3.94	3.22	11.39	6.30	0.156	0.180	0.061
Design Capacity (MW)	200	1356	1200	1620	1400	250	15	13

Table A.4: Features of the High and the Old Aswan Dams

	High Aswan Dam	Old Aswan Dam
Maximum Level, m	178	113
Maximum Storage, bcm	137.5	0.10
Minimum Level, m	147	107.5
Minimum Storage, bcm	31.6	0.044
Installed Power Capacity, MW	2100	621

Table A.5. Water Withdrawal Locations and Annual Amounts

		Water Demand Target Levels		
Location	**Current**	**Low**	**Medium**	**High**
Lake Victoria Basin	0	5	7.5	10
Sudd (Mongala)	0	1.5	3	4.5
Gebel el Aulia	1.5	1.5	1.5	1.5
Lake Tana Basin	0	1	2	3
Karadobi Basin	0	0.5	1	1.5
Mabil Basin	0	1.5	3	4.5
Border Basin	0	2	4	6
Sennar	15.62	19.62	23.62	27.62
Khashm el Girba	1.38	1.38	1.38	1.38
Lake Nasser	0	3	5	7.5
Downstream HAD	55.5	57.5	60.5	63

Appendix B

Baseline Climate Assessment Results

Baseline Climate Assessment Results

This appendix presents detailed Nile-DSS results for the baseline climate scenario. As in Section 5, the results are summarized relative to the following basin response measures:

- Water supply deficits by country (or region);
- Energy generation (average and firm); and
- River flow availability at representative locations throughout the basin.

The basin response is measured in an average sense as well as in its entire variability range, including extreme drought and flood episodes. It is important to note that the baseline climate scenario is not identical to the historical climate scenario. Instead, it is the climate scenario generated *for* the historical period by the HadCM2 General Circulation Model. For this reason, the basin response measures are only meaningful *relative* to the current demand targets.

B.1 Water Supply Deficits

Average Annual Deficits

Figure B.1.1 includes three graphs summarizing the results for current, low demand targets, and high demand targets. Each graph reports the expected water deficit associated with each development scenario for the countries of the Equatorial Lake sub-basin (i.e., Uganda, Rwanda, Tanzania, Kenya, Congo, and Burundi), Ethiopia/Eritrea, Sudan, and Egypt.

The most notable **broad observations** are that (a) water deficits increase as water demand targets increase from current to high (vertical comparison across the three graphs from top to bottom), and (b) for a particular demand target, water deficits decrease in scenarios with basin-wide cooperation (horizontal comparison from left to right). This conclusion is evident by the magnitude of the total basin-wide deficits.

For example, at the current target level and the no-cooperation scenario (Scenario I), basin-wide deficits amount to 6.8 billion cubic meters (bcm) per year. At the low demand target level, the deficit for the same scenario increases to 17.3 bcm, and at the high demand target level, the deficit reaches 30.8 bcm. Similar observations apply to all other scenarios.

Furthermore, considering the low demand target level (second graph of Figure B.1.1), basin-wide water deficits decrease in scenarios with higher basin-wide cooperation from 17.3 bcm per year to 6.1 bcm per year. Comparing this result with the current condition (6.8 bcm annual deficit), one concludes that despite the increased withdrawals, basin-wide shortages are not appreciably different than current conditions. At the high demand target level, however, with the exception of the Equatorial Lake region, real deficits are inevitable for all regions and scenarios.

More detailed observations can be noted by comparing the responses of the individual scenarios. Full development of the Blue Nile basin (Scenario II) practically eliminates water deficits in Ethiopia/Eritrea and Sudan. However, without water augmentation anywhere else in the basin, Egypt would experience serious water shortages. The wetland projects would reduce Egyptian deficits by 10 – 12 bcm per year. Scenario IV clearly shows that basin-wide cooperation strategies entail benefits for all.

The previous results can also be interpreted from **a different perspective**. As stated, the underlying hypothesis is that upstream withdrawals are fully satisfied first. In this regard, the deficits associated with Sudan and Egypt, the last of the water users, can be viewed as necessary adjustments to their absolute shares so that the stipulated scenario water allocations are feasible. Consider, for example, the low demand target level under Scenario I. Taken together, Egypt and Sudan are expected to experience a deficit of 12.8 bcm per year. Their target water allocation under this scenario is 5 bcm per year in addition to their present water use of 74 bcm per year. Thus, the assessment results imply that the *estimated* water use in these countries will have to be reduced by 7.8 bcm per year. Considering, however that the "current condition" also exhibits a 6.8 bcm deficit per year, the *actual* water use in Egypt and Sudan would have to be reduced by 1 bcm per year. On the other hand, under the basin-wide cooperation Scenario IV, the combined deficit of the two countries is 5.4 bcm per year, which implies that they can increase their current water use by 7.2 billion cubic meters per year. These conclusions, however, are valid in an average sense. What also needs to be addressed is the reliability with which the various demands are actually met. The reliability question relates to droughts and to deficit variability and is considered later in this section.

In **summary**, assuming that upstream water withdrawals are inevitable, this analysis indicates that basin-wide cooperation scenarios are much more beneficial to Sudan and Egypt than no cooperation scenarios. A similar conclusion can be drawn for Ethiopia and Sudan. The results show that in the presence of the five Ethiopian reservoirs, Sudan's water deficits are completely eliminated. Likewise, the interests of the Equatorial Lake countries, as well as those of all downstream water users, are better served when the lakes are fully regulated.

Deficits During Severe Droughts

Figure B.1.2 characterizes the basin response during severe droughts. Unlike the quantities of Figure B.1.1 which represents averages of many years, Figure B.1.2 depicts the deficits expected during an extreme drought year. (Deficits are measured relative to the water demand targets set by each scenario.) The three graphs of Figure B.1.2 correspond to current, low increase, and high increase demand targets. As the demand targets increase, water deficits also increase (vertical comparison). For a particular demand target, scenarios of increasing basin-wide cooperation result in significantly lower water deficits (horizontal comparison). Specifically, at the low demand target level, while no-cooperation (Scenario I) leads to a total basin-wide deficit of 51.1 bcm per year, full cooperation (Scenario IV) causes only a 34.3 bcm per year deficit. Thus, **cooperative water use strategies are especially important during droughts**. Similar observations can be made for the other demand target levels. From Egypt's and Sudan's perspectives, assuming that upstream water withdrawals will eventually develop, basin-wide cooperation scenarios are clearly advantageous. The same applies to Ethiopia and Sudan. The Lake Victoria region does not experience deficits for all scenarios.

Deficit Frequency Distribution

Figures B.1.3a, B.1.3b, B.1.3c, and B.1.3d provide **a full characterization of the annual water deficit variability** through the frequency curves in each region (Equatorial Lake countries, Ethiopia/Eritrea, Sudan, and Egypt). The curves indicate the frequency with which a certain annual deficit amount is exceeded. The largest and average deficits of each curve have already been discussed. Figure B.1.3a shows that there are no deficits in the Equatorial Lake region for all scenarios. Figure B.1.3b depicts the deficit frequency curves of Sudan and highlights the beneficial effect of Ethiopian development (Scenarios II and IV). Likewise, Figure B.1.3c shows that Ethiopian deficits can be greatly reduced under full development.

Figure B.1.3d depicts the deficit frequency curves for Egypt and validates the observations made earlier. Scenarios III and IV with a higher degree of basin-wide cooperation are clearly better than the other two scenarios.

Table B.1 summarizes the deficit statistics in numerical form.

B.2 Energy Generation

The development of hydropower sites along the Victoria Nile in Uganda and the Blue Nile in Ethiopia can greatly increase energy generation in the Nile Basin. The energy generation potential at these sites is now assessed as well as the overall energy benefit/impact of the water resources development and regulation projects.

Figure B.2.1 summarizes the **average annual energy generation** statistics by demand target level, scenario, and region. The regions include the Victoria Nile, the Blue Nile (in Ethiopia and Sudan), and the Aswan hydro-complex (in Egypt). The assessment results assume the full development of the Victoria Nile for Scenarios III and IV, which would yield annual energy generation of 14,758 GWH per year (Scenario III and IV; current demand targets). Similarly, full development of the Ethiopian Blue Nile would generate 30,744 GWH per year (Scenario II; current demand targets) for a combined Ethiopian-Sudanese output. Such a significant energy generation potential is an economic resource not only for Uganda and Ethiopia but for all of the Nile Basin.

Comparing the energy output at different demand targets, some interesting **sub-basin tradeoffs** are noted. For example, the energy generation in Ethiopia decreases by about 12,000 GWH per year as the demand targets increase from the current to the high target level. This reduction is due to the Ethiopian water withdrawals and the impact on river flow, posing a national decision tradeoff for Ethiopia: Increased water withdrawals benefit agriculture but can adversely impact the energy sector. To a milder degree, the same is true for Uganda and the Equatorial Lake region where the energy output of 14,758 GWH per year is reduced to 13,757 GWH per year when high upstream withdrawals take place. Lastly, the Aswan hydro-complex experiences significant energy generation loss for Scenarios I and II at higher demand targets. This energy loss is caused by a simultaneous reduction of turbine flow and a loss of turbine hydraulic head (lower reservoir water levels). The energy loss for Scenarios III and IV is milder due to the wetland evaporation reduction projects.

At the same demand target demand level, more hydropower development implies more energy generation. For example, basin-wide energy generation at the low demand target level increases from 11,149 GWh per year for Scenario I to 47,506 GWh per year for Scenario IV.

Figure B.2.2 is structured much like Figure B.2.1 except that it presents annual **firm energy generation** results. Firm energy generation is important because it can be guaranteed even under the most adverse hydrologic circumstances. The figure shows that firm energy generation is markedly affected by demand target increases. An extreme example is provided by the Blue Nile under Scenario II. Firm energy generation declines from 12,927 GWh per year at the current demand target level to 4,767 GWh per year at the high demand target level. On the other hand, firm energy on the Victoria Nile is much more reliable due to the presence of Lake Victoria.

Figure B.2.3 shows the annual **energy generation frequency curves** for the three regions being discussed. Figure B.2.3a presents the frequency curves for the Victoria Nile and shows the ability of the decision system to modify their shape from very variable (Scenarios I and II) to fairly uniform (Scenarios III and IV). Figure B.2.3d shows the basin-wide energy generation frequency curves for current, low, and high demand targets, and re-emphasizes that basin-wide hydropower development and cooperative regulation entail distinct benefits for all Nile Basin Nations.

Tables B.2.1 and B.2.2 summarize the energy statistics by station as well as by sub-basin in numerical form.

B.3 River Flow Availability

River flow changes under various demand targets and management scenarios are another measure of the basin's capacity to serve its water users. Using the presentation framework adopted for the water deficits, the following are discussed: (a) average flow availability at representative basin locations; (b) minimum and maximum flows pertaining to most severe droughts and floods; and (c) flow frequency curves providing a full characterization of the expected flow variability.

Average Flows

Figure B.3.1 presents the average flows predicted at representative basin locations for current, low demand increase, and high demand increase targets and the various scenarios being investigated. Results are presented for the exit of Lake Albert, Malakal (downstream of the White Nile junction with the Sobat River), the Blue Nile at Khartoum, and Dongola (near the entrance of Lake Nasser).

The figure shows that **as demand targets increase, river flows at all locations decrease**. Specifically, in Scenario I, the annual average flow at Khartoum decreases by nearly 5.5 bcm per year from the low to the high demand target level (i.e., from 27.0 to 21.5 bcm per year) as a result of water consumption in Ethiopia. Under the same conditions, the flow at Dongola decreases by 7.4 bcm from 60.5 to 53.1 bcm per year.

Comparing the scenarios at the current demand targets, one can again distinguish the different response of the four scenarios. The flows of Scenarios I and II are virtually the same. The difference in the two scenarios is whether the Blue Nile Basin is in current condition or fully developed. Development affects the flow at Khartoum (due to reservoir evaporation) and, consequently, the flow at Dongola. However, these effects are minimal. Scenario III includes the wetland projects and the regulation of the Equatorial Lakes. These scenarios produce a significant flow increase at Malakal from 33.16 to 47.5 bcm per year. The same increase carries over at Dongola where the flow increases by almost 14.2 bcm per year from 60.5 (Scenario I) to 74.7 bcm per year (Scenario III). Lastly, under the full cooperation Scenario IV, the flow at Malakal remains the same while the flow at Dongola exhibits a 0.9 bcm reduction due to the evaporation and transmission loss along the Blue Nile. The previous figures imply that the wetland projects augment the downstream flow by about 14.2 billion cubic meters per year.

Similar observations apply to the low and high demand increases. An exception occurs on the Khartoum flows. When all Ethiopian reservoirs are on line, the extra storage helps to satisfy the Ethiopian demands and eliminate water deficits. As a result, downstream flow is reduced.

Minimum and Maximum Flows

Figure B.3.2 shows the minimum annual flows predicted at the previous locations during the **most severe drought** of the assessment period. (The year of the most severe drought may vary across the demand targets, across the scenarios of the same target, and across the locations of the same scenario.) As a general observation, the flow decreases as the demands increase from low to high.

Comparing the scenarios at the same demand targets, the no-cooperation scenarios lead to lower flows than the scenarios including basin-wide development and more cooperation. This can be observed by comparing the flows of Scenarios I and IV at the current and low demand targets. All locations experience higher minimum flows under Scenario IV, with the most notable increase recorded at Dongola where the minimum flow increases from 22.22 to 41.5 bcm per year. The higher flows at Khartoum in Scenarios II and IV are direct consequence of more storage in Ethiopia. This storage supports higher river flows and helps mitigate the drought impacts for Ethiopia as well as for Sudan and Egypt. Lastly, the increase of the minimum outflow from Lake Albert shows that the Sudd is also an important beneficiary of cooperative management. Equatorial Lake regulation augments the minimum outflow from Lake Albert by 9.5 bcm per year, from 14.1 (Scenario I) to 23.6 bcm per year (Scenario IV). At the high demand target, Lake Albert's outflow under unregulated conditions (Scenario I) would only amount to 10 bcm per year. By contrast, under lake regulation (Scenario IV), a significantly higher outflow of 19.2 bcm per year could be sustained. Thus, cooperative strategies augment the flows during droughts and help reduce their adverse consequences. Scenario IV accomplishes this by using coordinated management schemes depending which sub-basin experiences a drought. In this regard, the larger storage projects (Lake Victoria, Lake Albert, Lake Tana, Karadobi, and Lake Nasser) are key elements of a basin-wide drought management plan. The decision system implemented in this investigation is an example of an effective dynamic management scheme designed to continually update itself to the hydrologic conditions of the basin.

At the other hydrologic extreme, **floods**, the goal is to prevent very high and damaging flows. This can only be accomplished through the coordinated use of reservoir storage. Figure B.3.3 presents the maximum annual flows at the above-mentioned locations over the assessment record. As expected, the figure shows that flood flows are reduced when higher withdrawals take place (comparison across the three graphs). Furthermore, the individual graphs at each demand target demonstrate that basin-wide cooperative strategies are beneficial to flood management. Consider, for example, the outflow from Lake Albert in Scenarios I and IV. The maximum annual outflow from the lake decreases from 51.7 to 38.5 bcm per year. In this instance, the decision system utilizes the storage of the Equatorial Lakes to reduce the outflow from Lake Albert. Outflow reduction benefits the Sudd as well as all downstream riparians. High flows create more extensive permanent swamp areas, disabling the use of agricultural and pastoral lands and forcing extensive population migrations. Thus, Equatorial Lake regulation can ensure that long term land use in the Sudd remains intact and prevent disruptive population migrations. In fact, the assessment shows that with proper seasonal management, the wetland development projects in connection with the regulation of the Equatorial Lakes benefit the Sudd in all hydrologic circumstances--droughts, floods, and normal periods. Lake storage and the Jonglei Canal can be used to augment the flow during droughts, reduce the threat of floods, and support seasonal wetlands at all times. Further downstream, the flow reduction in wet years also benefits Egypt by reducing the flow at Dongola and preventing excess water spillage.

Flow Frequency Distribution

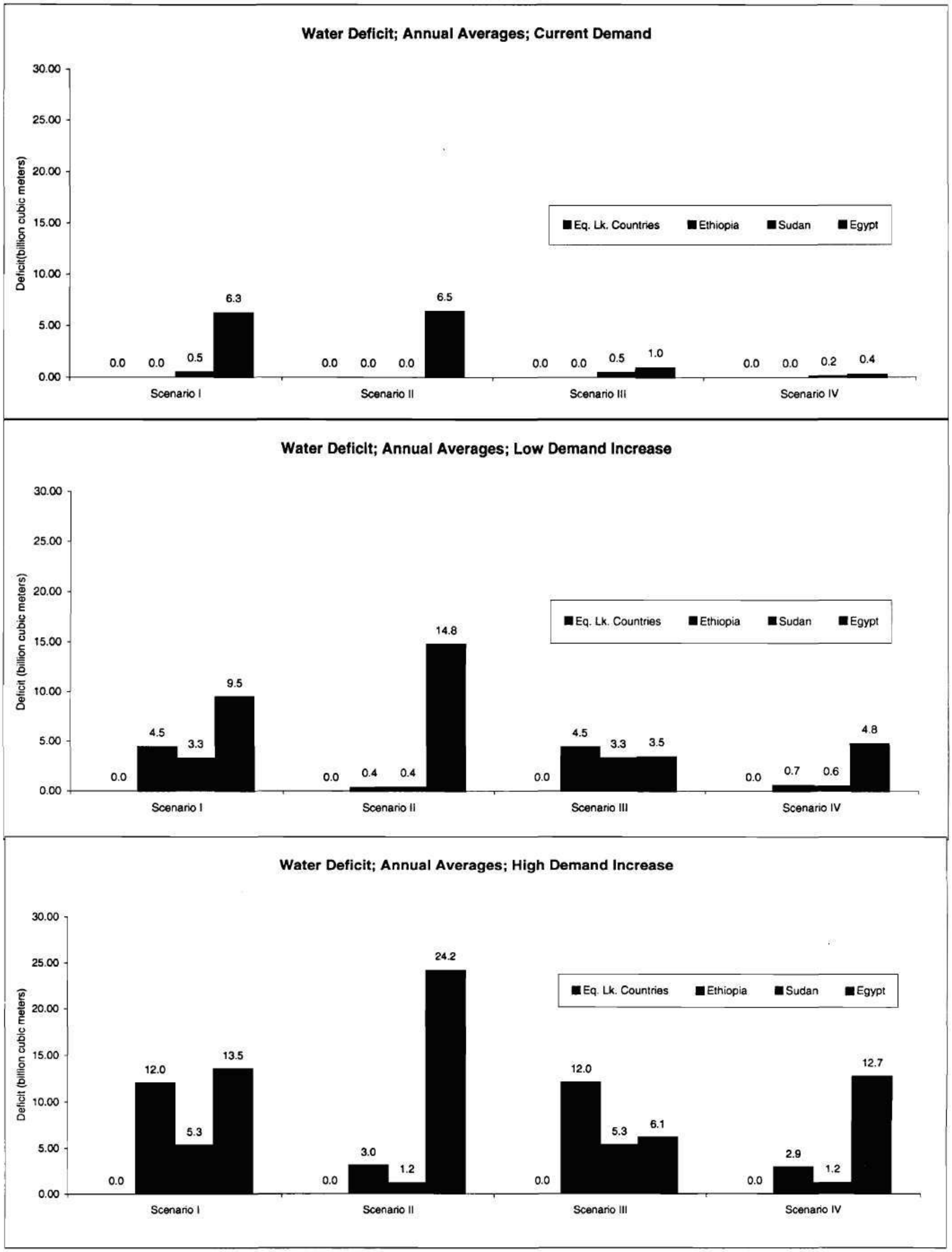
Figures B.3.4a, B.3.4b, B.3.4c, and B.3.4d depict the entire flow frequency curves at the same locations (Lake Albert, Malakal, Blue Nile at Khartoum, and Dongola). The curves for Lake Albert (Figure B.3.4a) show that in the scenarios of higher basin-wide cooperation, the decision system manages to maintain a more uniform annual flow from Lake Albert during all times. As stated, more uniform flow benefits the Sudd as well as the downstream riparians. In this regard, the frequency curve of Scenario IV is most desirable because it promises lower maximum and higher minimum flows. In Figure B.3.4b, the frequency curves at Malakal are shifted toward higher values from Scenario I to Scenario IV as a result of the additional flow generated by the wetland conservation projects and the regulation of the Equatorial Lakes. Figure B.3.4c presents the flow frequency curve of the Blue Nile at Khartoum and shows that with full development in

Ethiopia the flows are less variable. This is evident in Scenarios II and IV. Lastly, the frequency distributions of the flow at Dongola (Figure B.3.4d) indicate that basin-wide cooperation scenarios lead to higher and less variable flows.

Flow and Storage Sequences

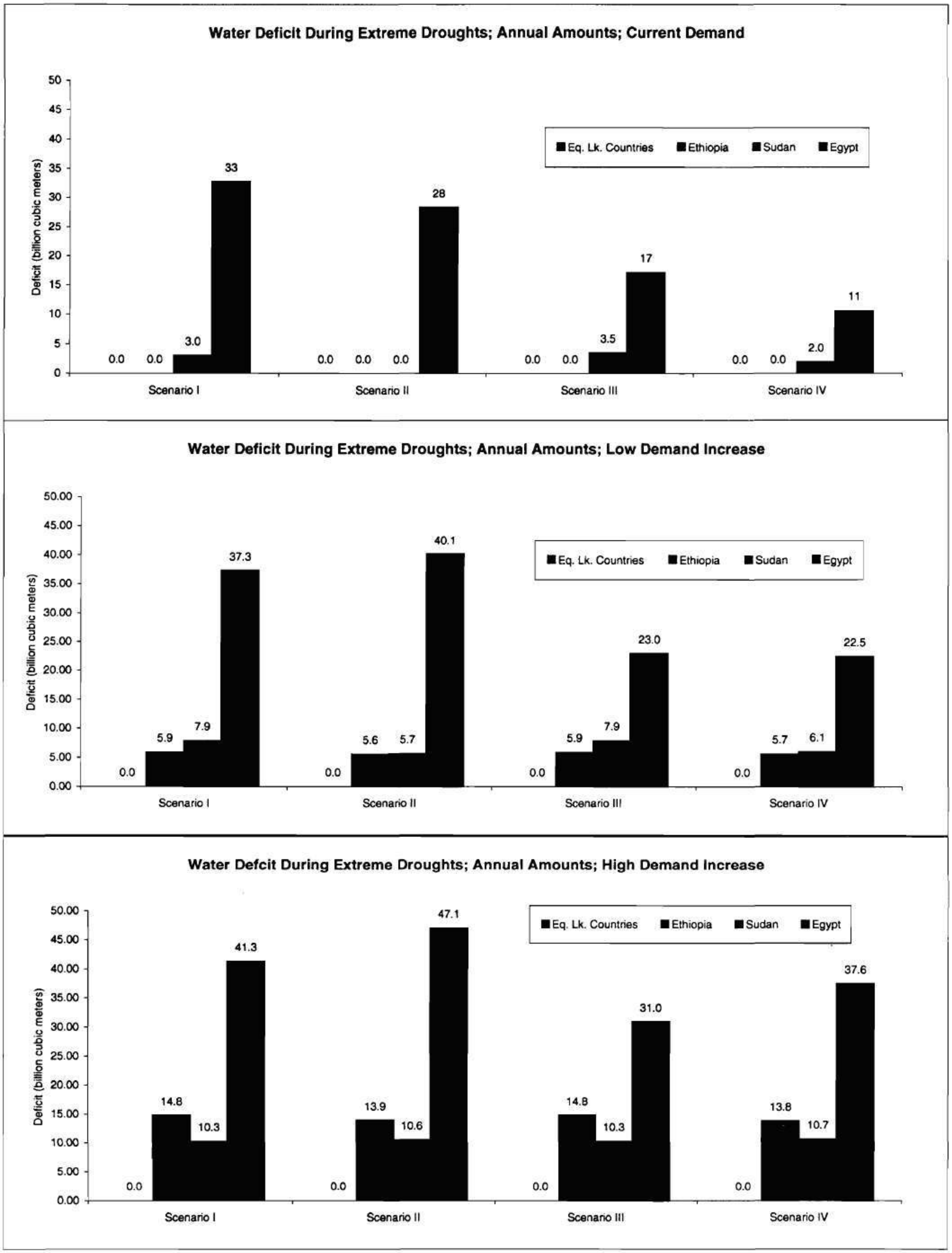
The flow frequency curves are derived from the 10-day flow sequences generated by the decision system for these and other locations in the basin. The sequences at Malakal, Blue Nile at Khartoum, Dongola, and the exit of Lake Nasser for Scenario IV are plotted in Figure B.3.5. Such data are useful to determine the **seasonal flow changes expected under each scenario** and to assess the costs and benefits associated with short-term flow rates rather than annual volumes. Consider, for example, the Blue Nile flow sequences at Khartoum under Scenario IV for the current demand targets. The figures show that the Ethiopian reservoirs can exercise a high degree of flow regulation benefiting the downstream users both during droughts as well as floods. As a result, the flow at Dongola (same figures) becomes less variable and more dependable. The existence of a sizeable storage in Ethiopia can provide extra security to Egypt during very dry years. The corresponding reservoir levels for Lake Victoria, Karadobi, Sennar, and HAD are shown on Figure B.3.6.

Tables B.3.1 and B.3.2 include flow statistics for all major basin sites and scenarios.



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.1.1: Deficit; Annual Average; Baseline



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.1.2: Deficit During Extreme Droughts; Annual Amounts; Baseline

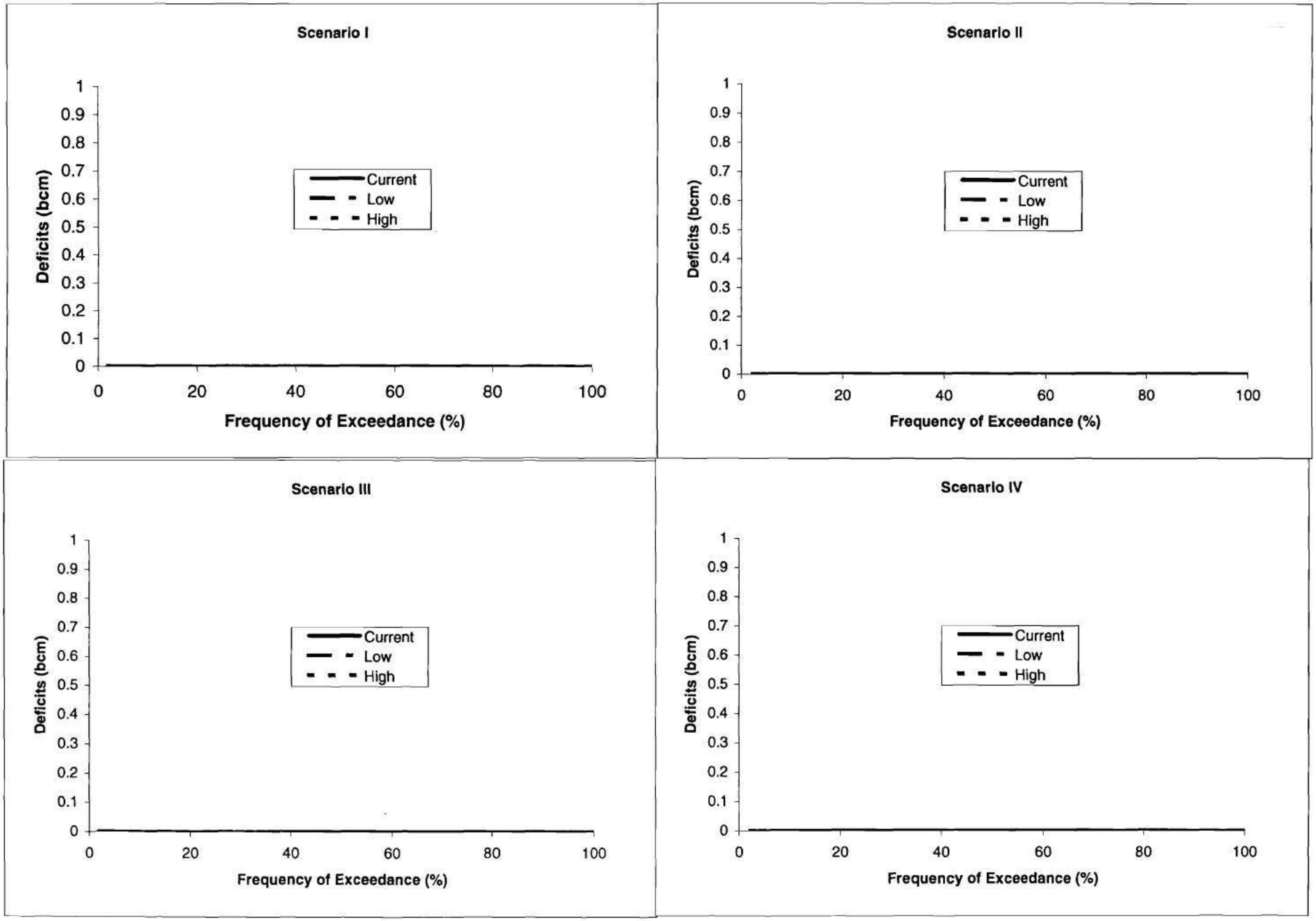


Figure B.1.3a: Annual Deficit Frequency Curves; Equatorial Lake Region; Baseline

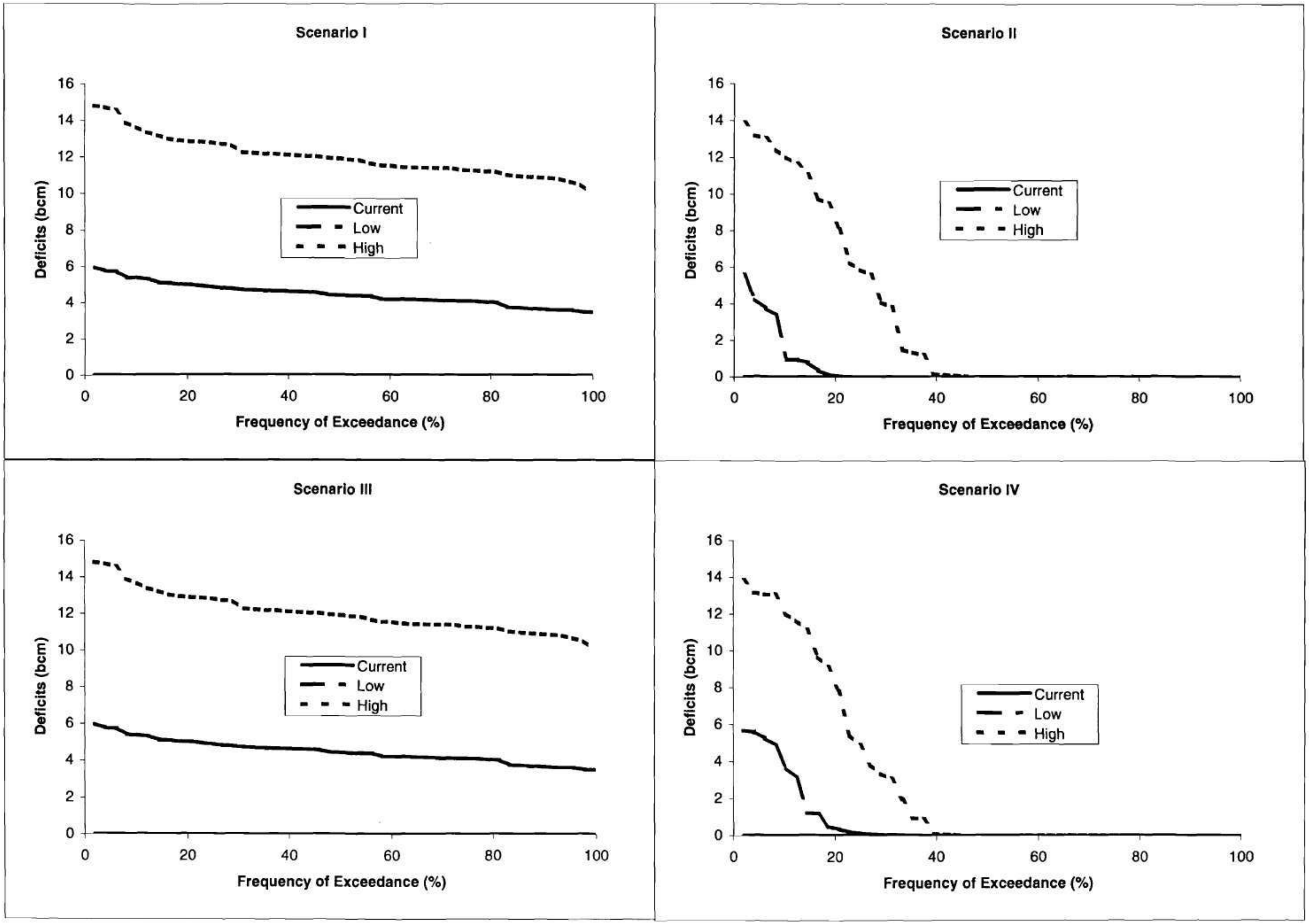


Figure B.1.3b: Annual Deficit Frequency Curves; Ethiopia/Eritrea; Baseline

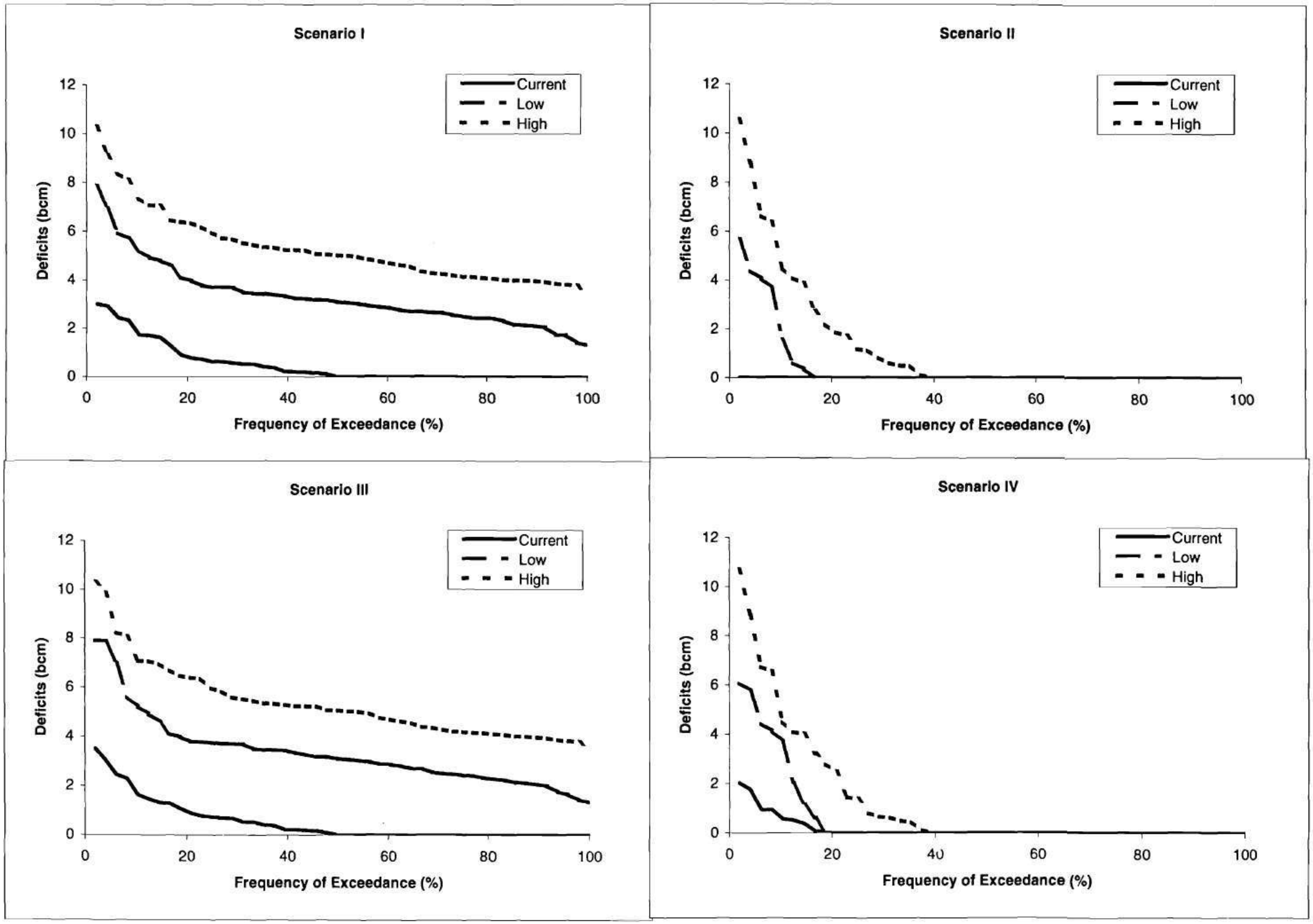


Figure B.1.3c: Annual Deficit Frequency Curves; Sudan; Baseline

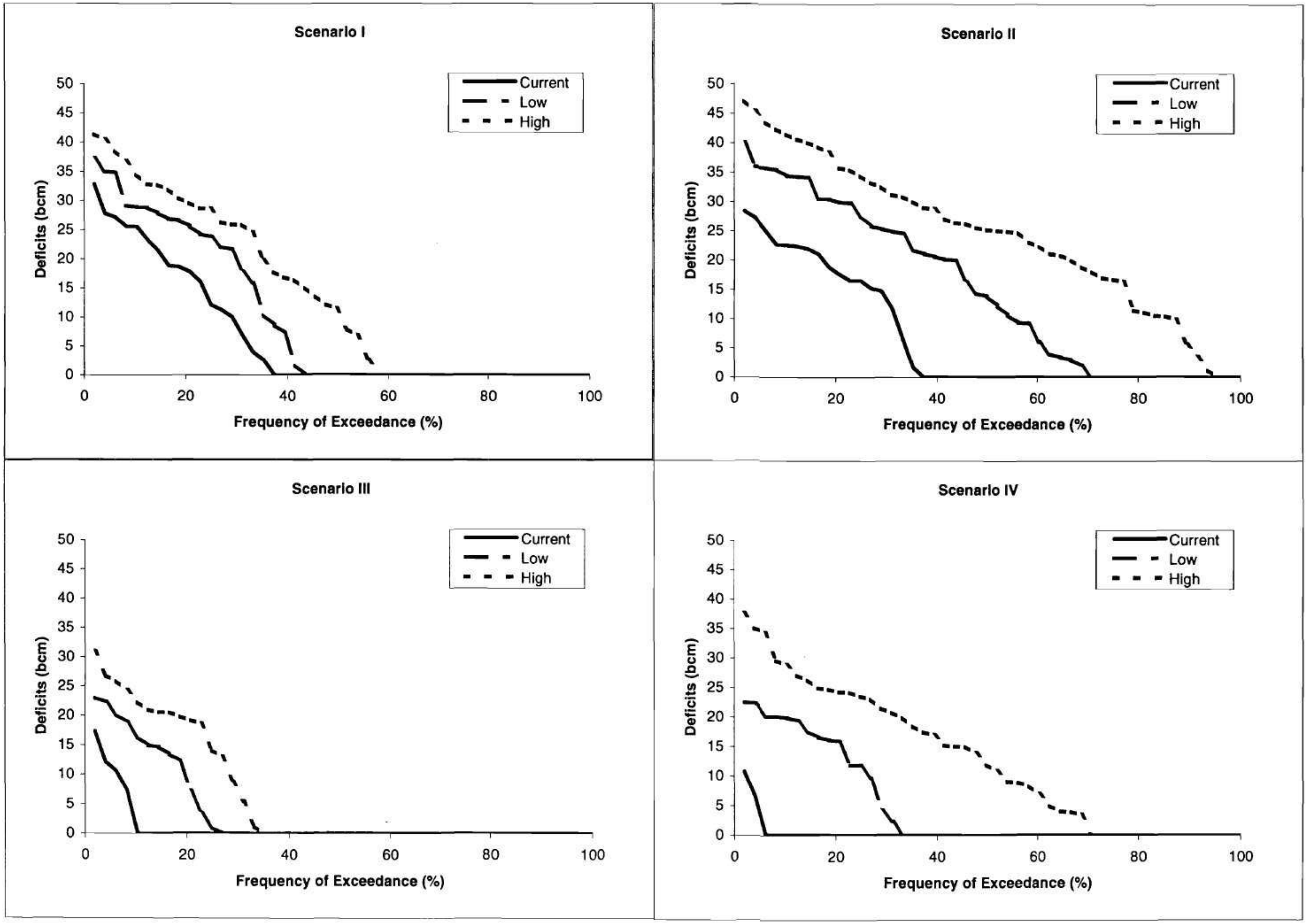
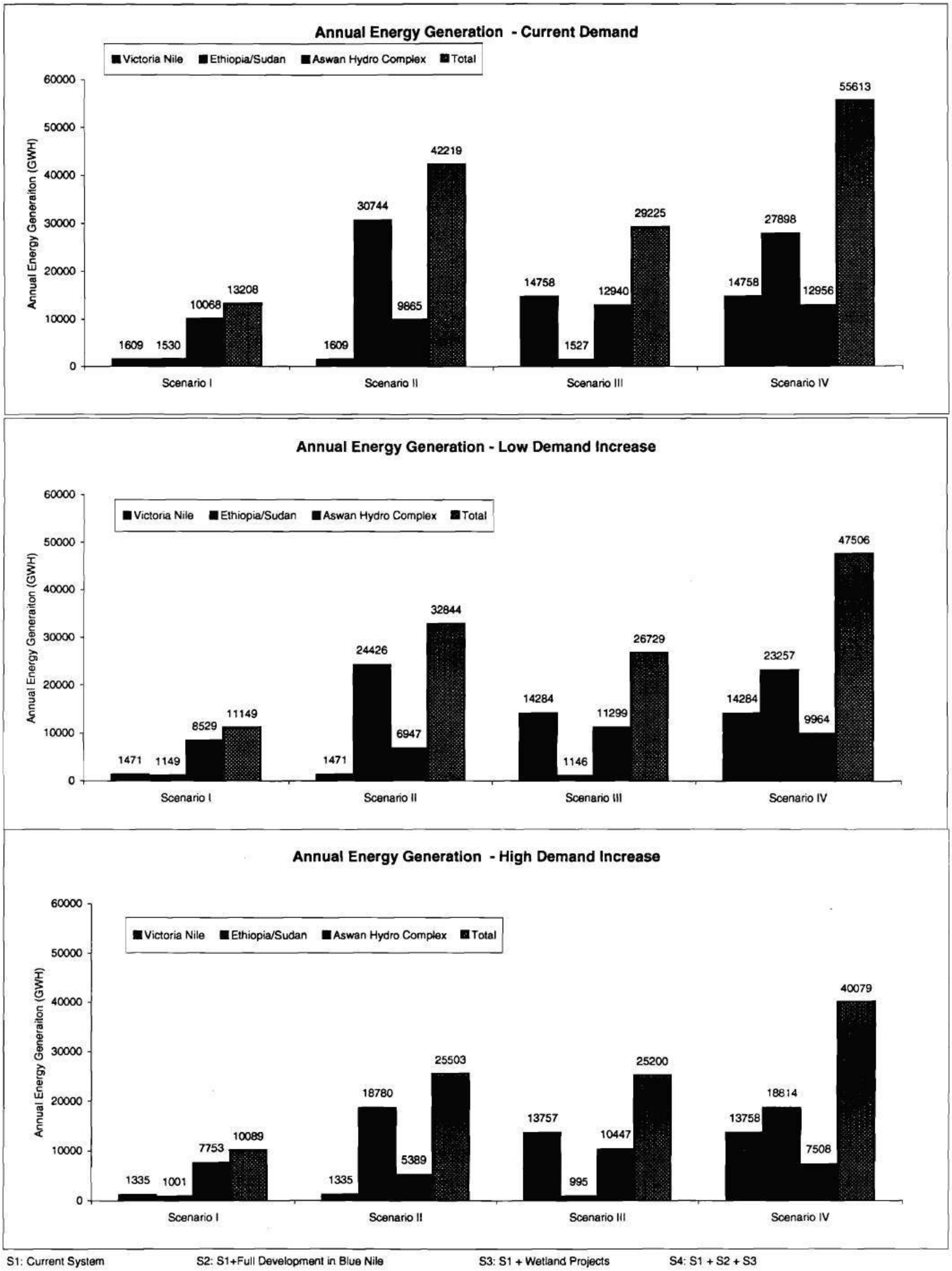


Figure B.1.3d: Annual Deficit Frequency Curves; Egypt; Baseline

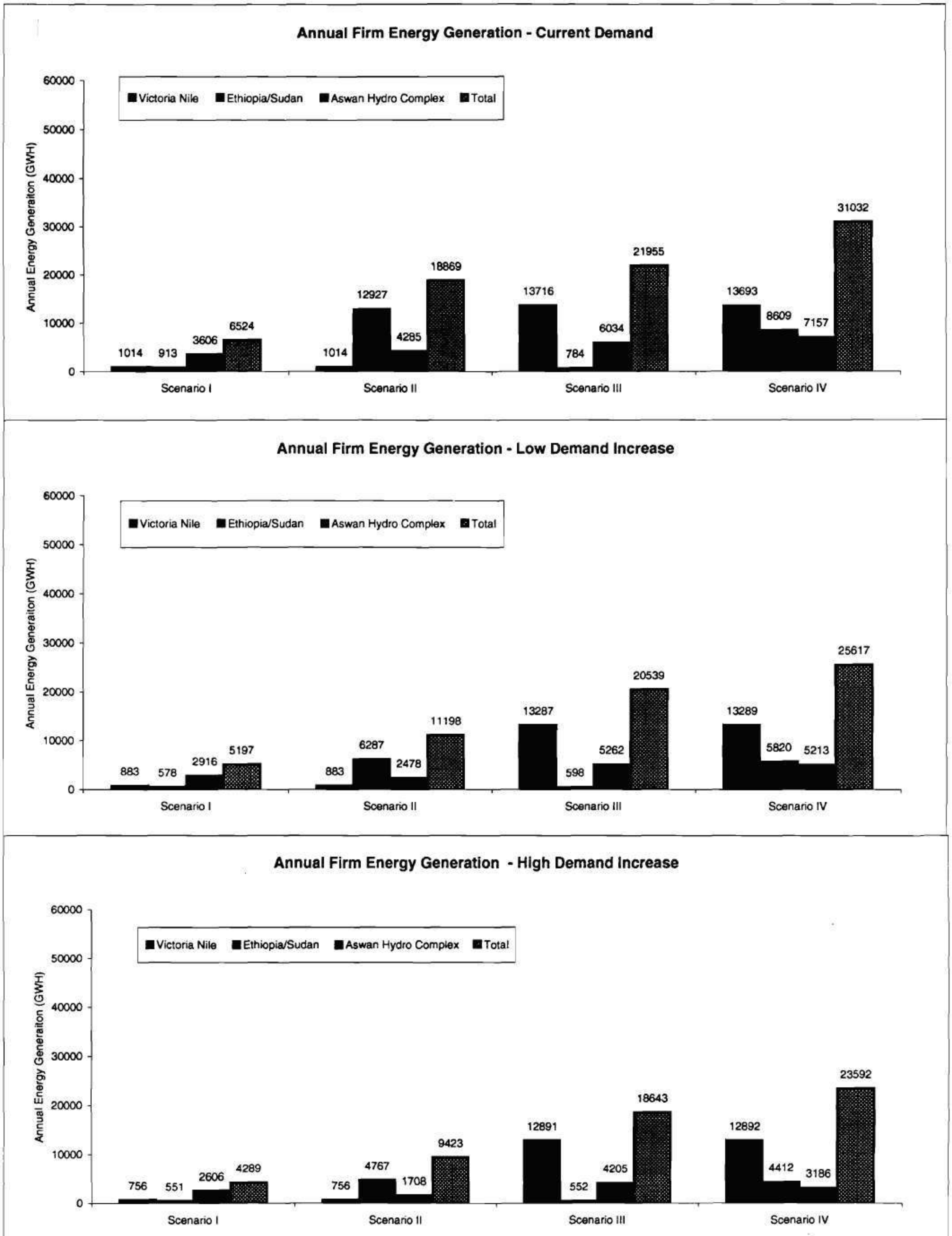
Table B.1: Nile Basin Assessment: Annual Average Deficit Statistics (Baseline)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mongala	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gabel Aulia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tana	0.00	0.51	1.32	0.00	0.02	0.26	0.00	0.51	1.32	0.00	0.05	0.25
Karadobi	0.00	0.20	0.70	0.00	0.02	0.22	0.00	0.20	0.70	0.00	0.04	0.23
Mabil	0.00	1.41	3.76	0.00	0.14	1.06	0.00	1.41	3.76	0.00	0.23	0.94
Mendaia	0.00	0.23	0.76	0.00	0.04	0.24	0.00	0.23	0.76	0.00	0.06	0.24
Border	0.00	2.12	5.50	0.00	0.21	1.23	0.00	2.12	5.50	0.00	0.29	1.25
Sennar	0.50	3.33	5.30	0.00	0.43	1.21	0.51	3.34	5.33	0.15	0.58	1.25
Girba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HAD Upstream	0.00	0.01	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
HAD Downstream	6.29	9.45	13.50	6.48	14.75	24.22	0.99	3.49	6.09	0.36	4.80	12.72



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.2.1: Annual Average Energy Generation; Baseline



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.2.2: Annual Firm Energy Generation; Baseline

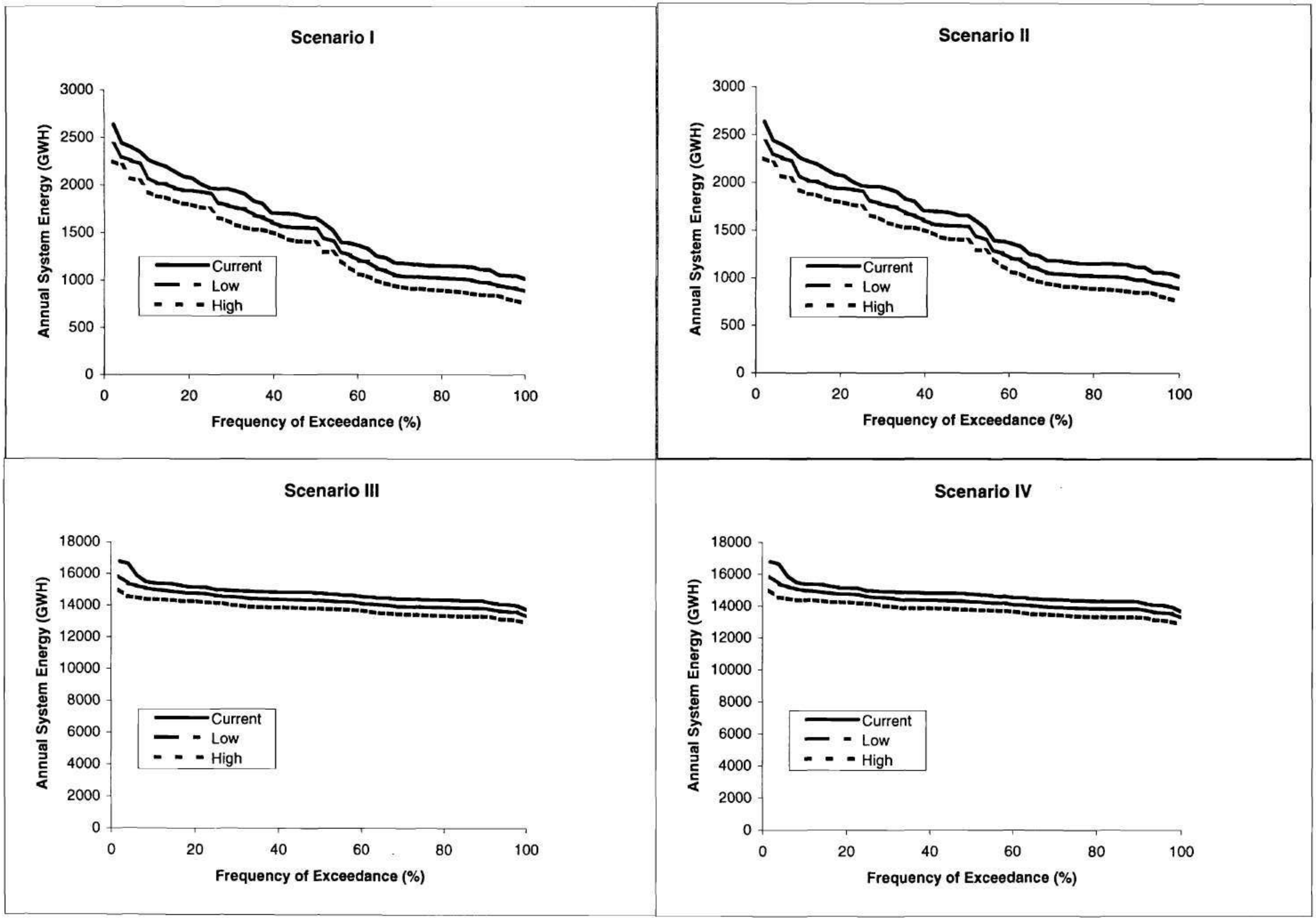


Figure B.2.3a: Annual Energy Frequency Curves; Victoria Nile; Baseline

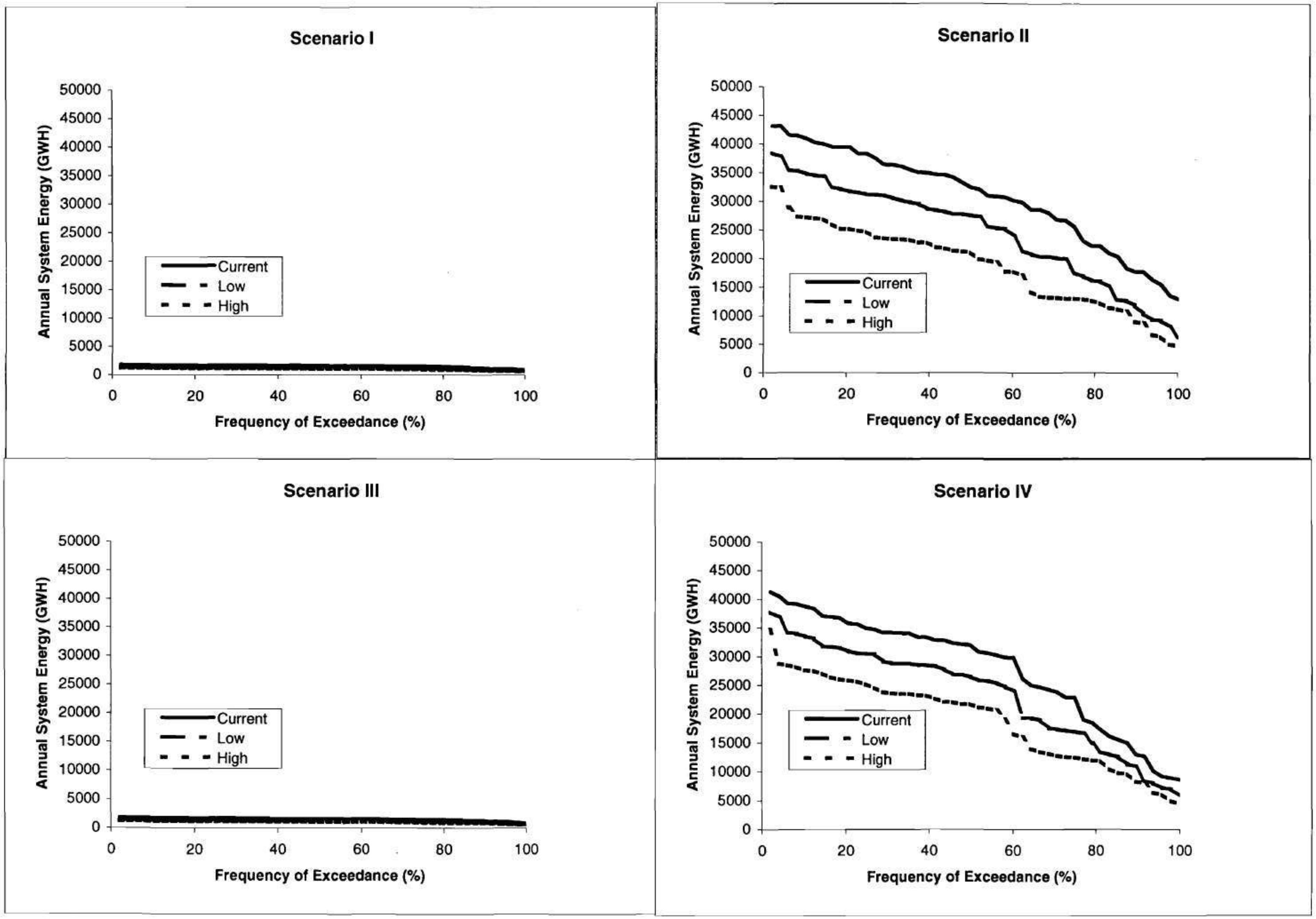


Figure B.2.3b: Annual Energy Frequency Curves; Ethiopia/Sudan; Baseline

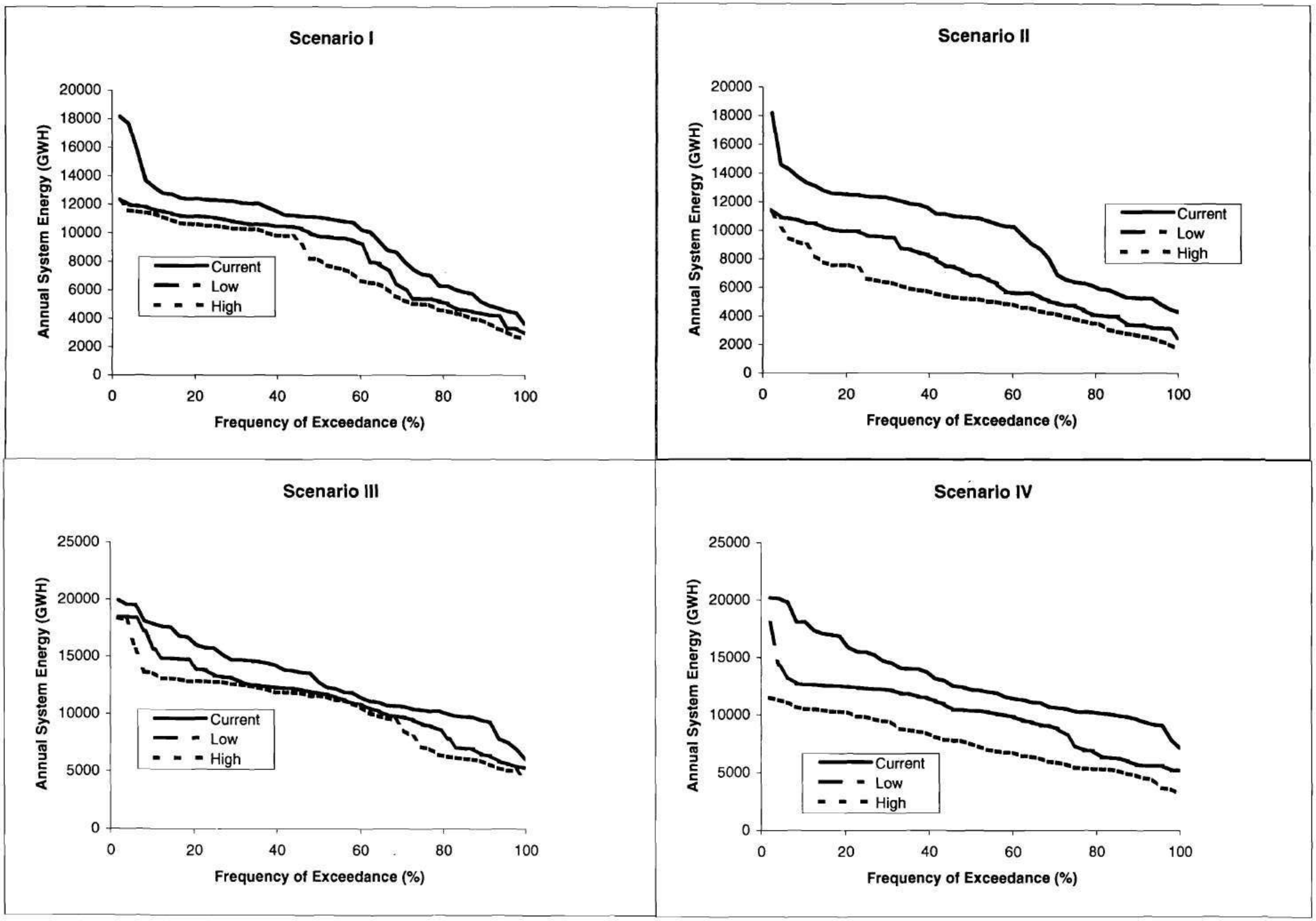


Figure B.2.3c: Annual Energy Frequency Curves; HAD Hydro Complex; Baseline

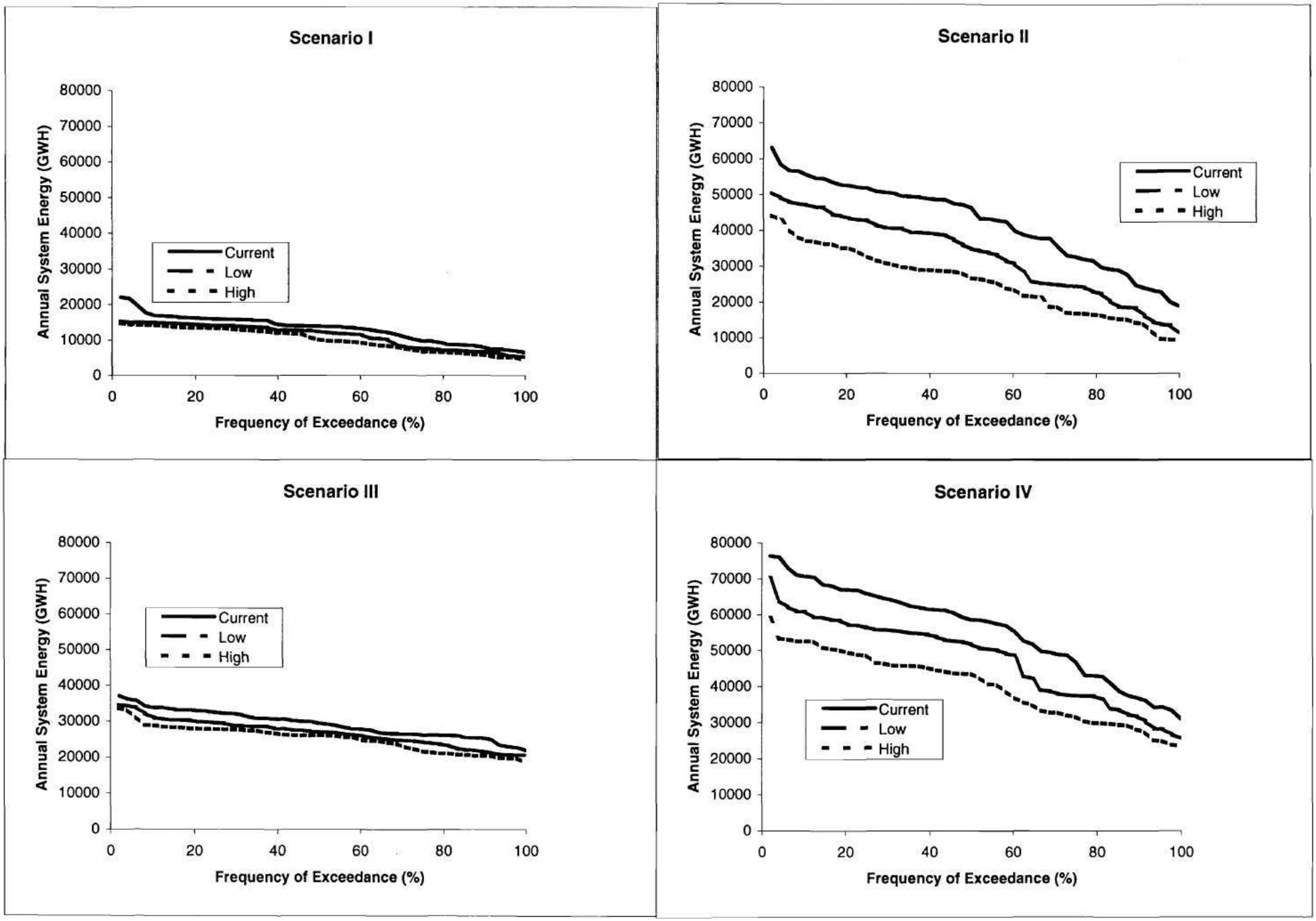


Figure B.2.3d: Annual Energy Frequency Curves; Total System; Baseline

Table B.2a: Nile Basin Assessment: Average Annual Energy (GWH) Statistics (Baseline)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Owen Falls	1609	1471	1335	1609	1471	1335	1635	1492	1349	1635	1492	1349
Bujagali	0	0	0	0	0	0	1437	1310	1182	1437	1310	1182
Kalagala	0	0	0	0	0	0	1753	1596	1440	1753	1596	1440
Kamdini	0	0	0	0	0	0	1571	1524	1424	1571	1524	1424
Ayago South	0	0	0	0	0	0	2665	2665	2665	2665	2665	2665
Ayago North	0	0	0	0	0	0	2051	2051	2051	2051	2051	2051
Murchison	0	0	0	0	0	0	3647	3647	3647	3647	3647	3647
Subtotal	1609	1471	1335	1609	1471	1335	14758	14284	13757	14758	14284	13758
Lake Tana	0	0	0	1498	1212	972	0	0	0	1484	1225	953
Karadobi	0	0	0	6014	4551	2773	0	0	0	3695	3168	2649
Mabil	0	0	0	5533	4148	2846	0	0	0	4754	3902	3043
Mendaia	0	0	0	9112	7656	6645	0	0	0	9186	7792	6549
Border	0	0	0	6529	5038	3979	0	0	0	6593	5170	3959
Subtotal	0	0	0	28686	22605	17215	0	0	0	25712	21258	17153
Roseires	1375	1048	917	1886	1656	1418	1371	1046	911	2018	1839	1514
Sennar	115	59	43	131	124	106	115	59	43	126	119	106
K. Girba	41	41	41	41	41	41	41	41	41	41	41	41
Subtotal	1530	1149	1001	2058	1821	1565	1527	1146	995	2186	1999	1661
HAD (GWH)	10068	8529	7753	9865	6947	5389	12940	11299	10447	12956	9964	7508
Total	**13208**	**11149**	**10089**	**42219**	**32844**	**25503**	**29225**	**26729**	**25200**	**55613**	**47506**	**40079**

Table B.2b: Nile Basin Assessment: Annual Firm Energy (GWH) Statistics (Baseline)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Owen Falls	1014	883	756	1014	883	756	1272	1128	1003	1265	1129	1003
Bujagali	0	0	0	0	0	0	1132	1003	892	1125	1004	892
Kalagala	0	0	0	0	0	0	1378	1222	1086	1369	1222	1086
Kamdini	0	0	0	0	0	0	1505	1382	1257	1506	1382	1258
Ayago South	0	0	0	0	0	0	2663	2663	2663	2663	2663	2663
Ayago North	0	0	0	0	0	0	2050	2050	2050	2050	2050	2050
Murchison	0	0	0	0	0	0	3644	3644	3644	3644	3644	3644
Subtotal	1014	883	756	1014	883	756	13644	13092	12595	13622	13094	12597
Lake Tana	0	0	0	670	529	413	0	0	0	669	490	382
Karadobi	0	0	0	55	13	0	0	0	0	0	0	0
Mabil	0	0	0	1674	32	28	0	0	0	0	1	7
Mendaia	0	0	0	4733	2886	1850	0	0	0	3550	2769	1816
Border	0	0	0	3383	1867	1242	0	0	0	2600	1788	1222
Subtotal	0	0	0	10515	5326	3534	0	0	0	6820	5047	3428
Roseires	840	540	520	1544	698	461	712	559	520	977	676	453
Sennar	41	6	0	131	36	10	40	6	0	63	26	10
K. Girba	18	19	19	19	18	16	19	19	19	19	19	18
Subtotal	898	565	539	1694	751	486	771	584	539	1059	721	480
HAD (GWH)	3606	2916	2606	4285	2478	1708	6034	5262	4205	7157	5213	3186
Total	**5519**	**4365**	**3901**	**17509**	**9440**	**6484**	**20449**	**18938**	**17339**	**28658**	**24076**	**19691**

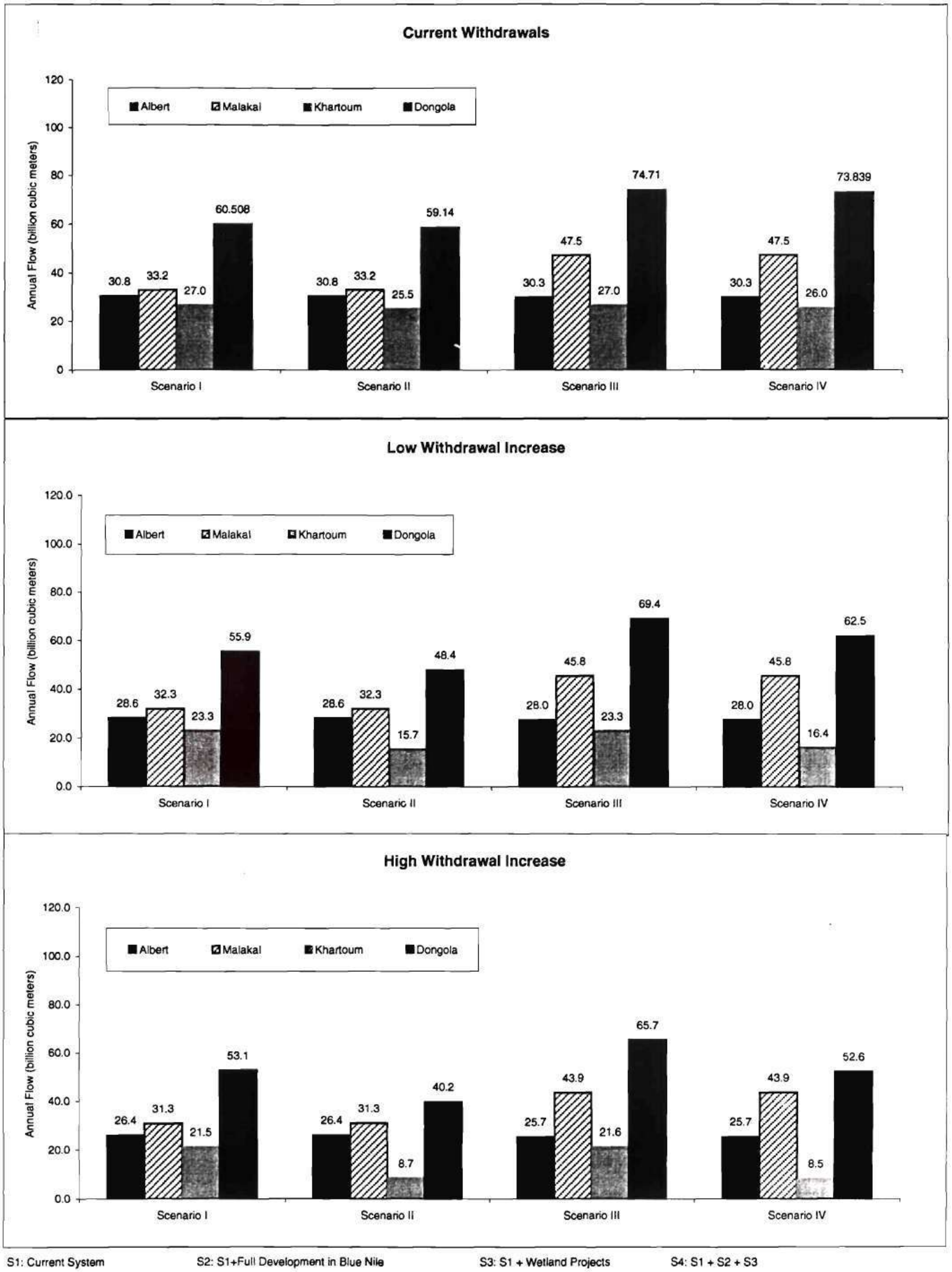
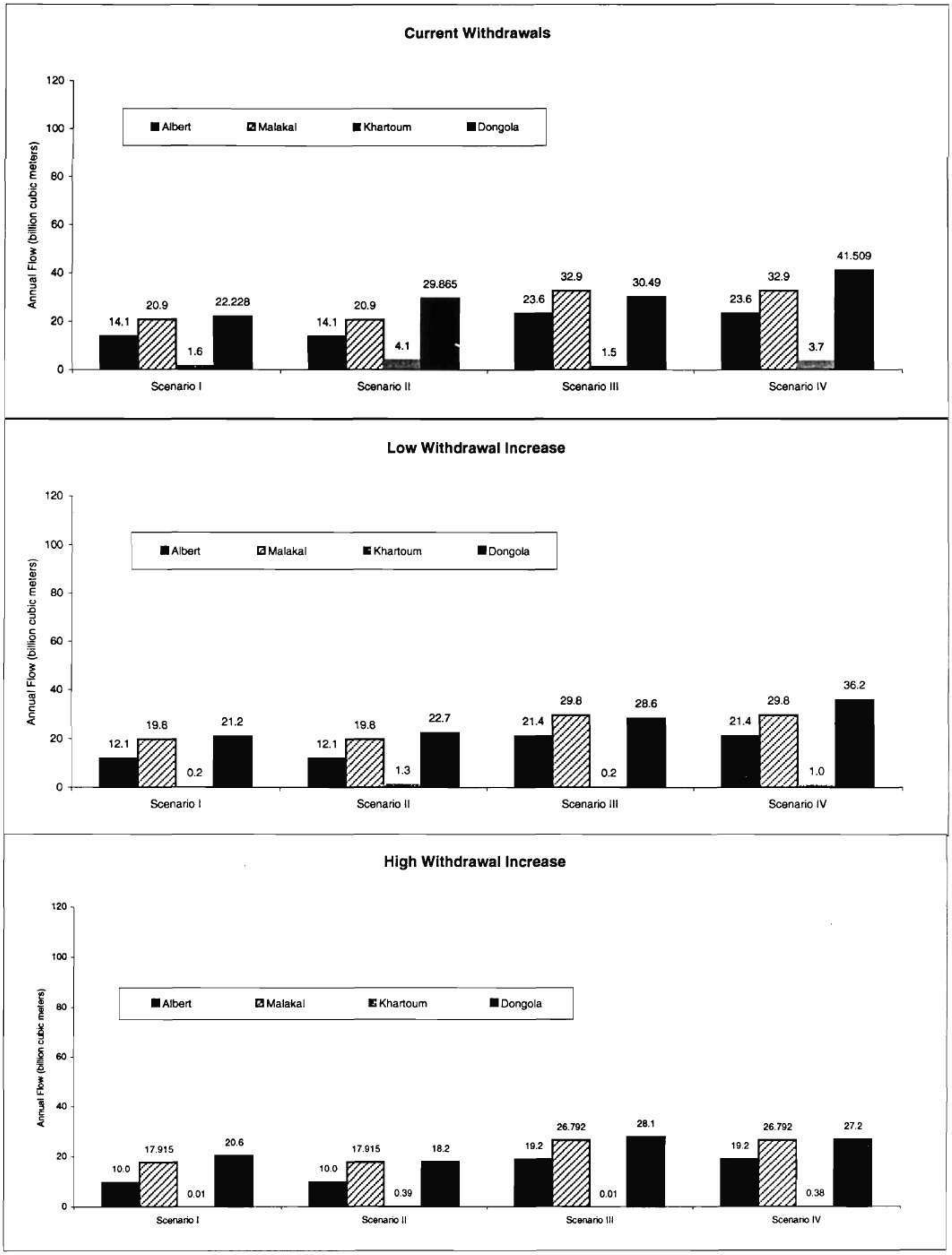
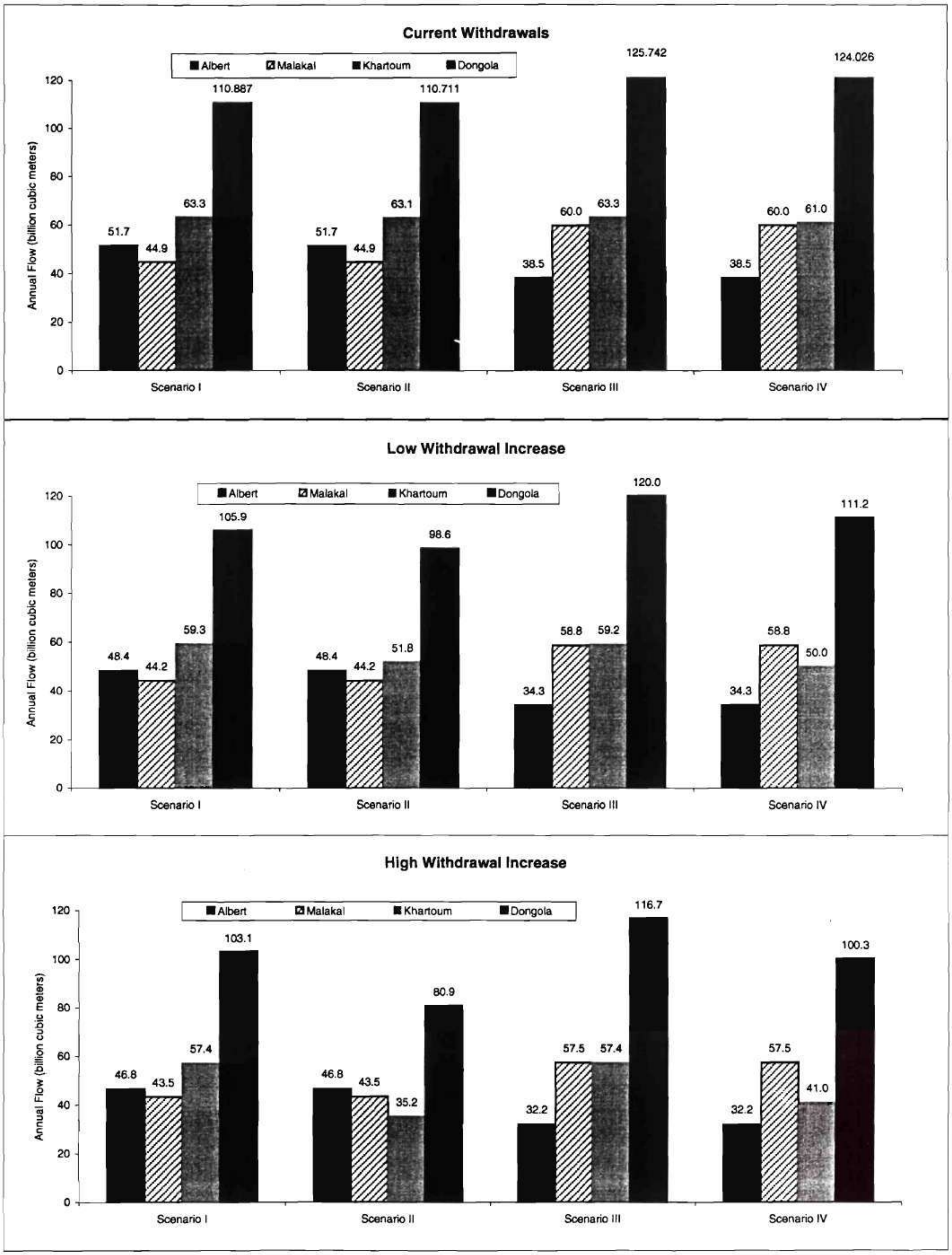


Figure B.3.1: Annual Average Flows at Representative Basin Locations; Baseline



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.3.2: Minimum Annual Flows at Representative Basin Locations;Baseline



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure B.3.3: Maximum Annual Flows at Representative Basin Locations; Baseline

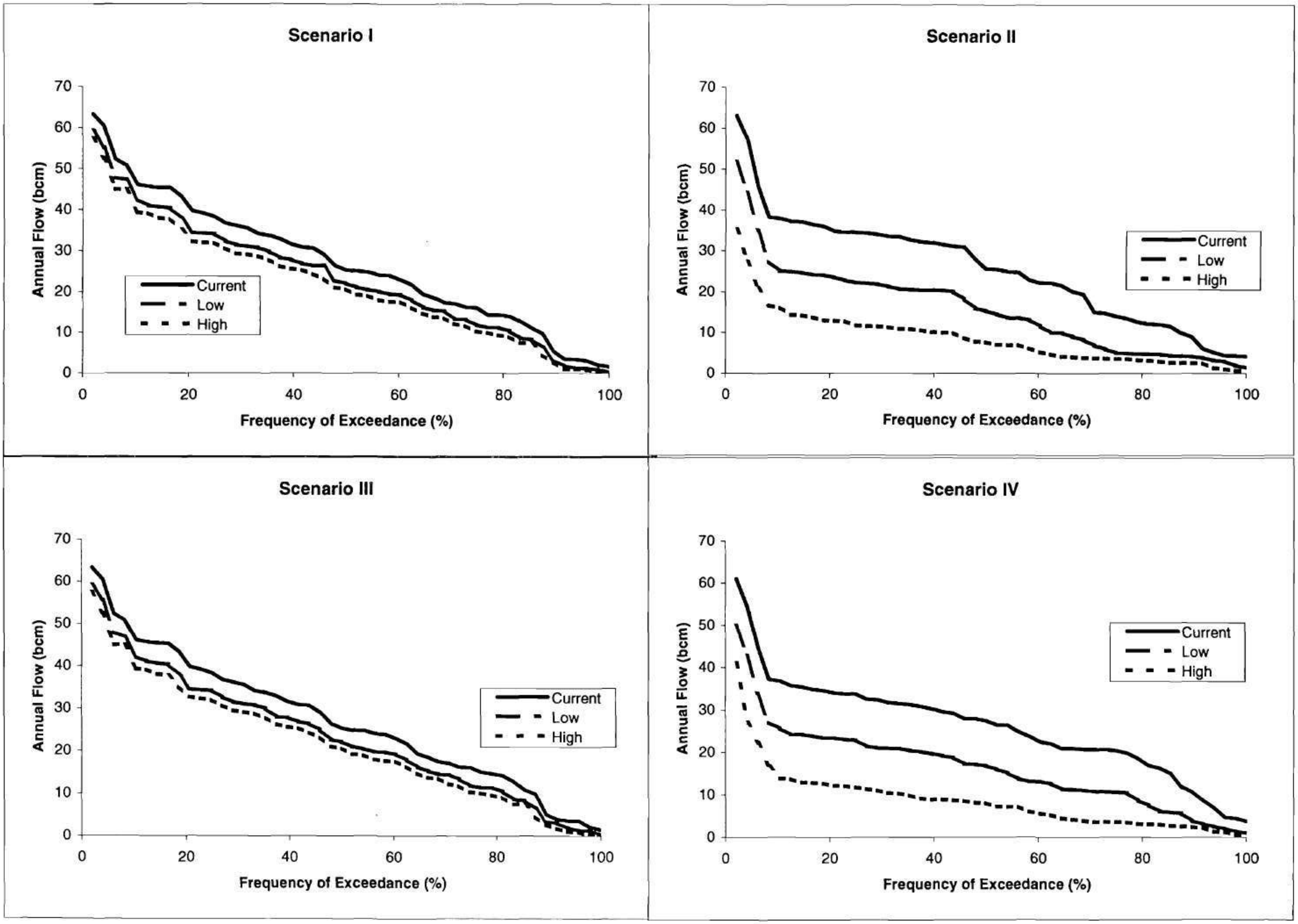


Figure 3.4c: Flow Frequency Curves; Khartoum Flows; Baseline

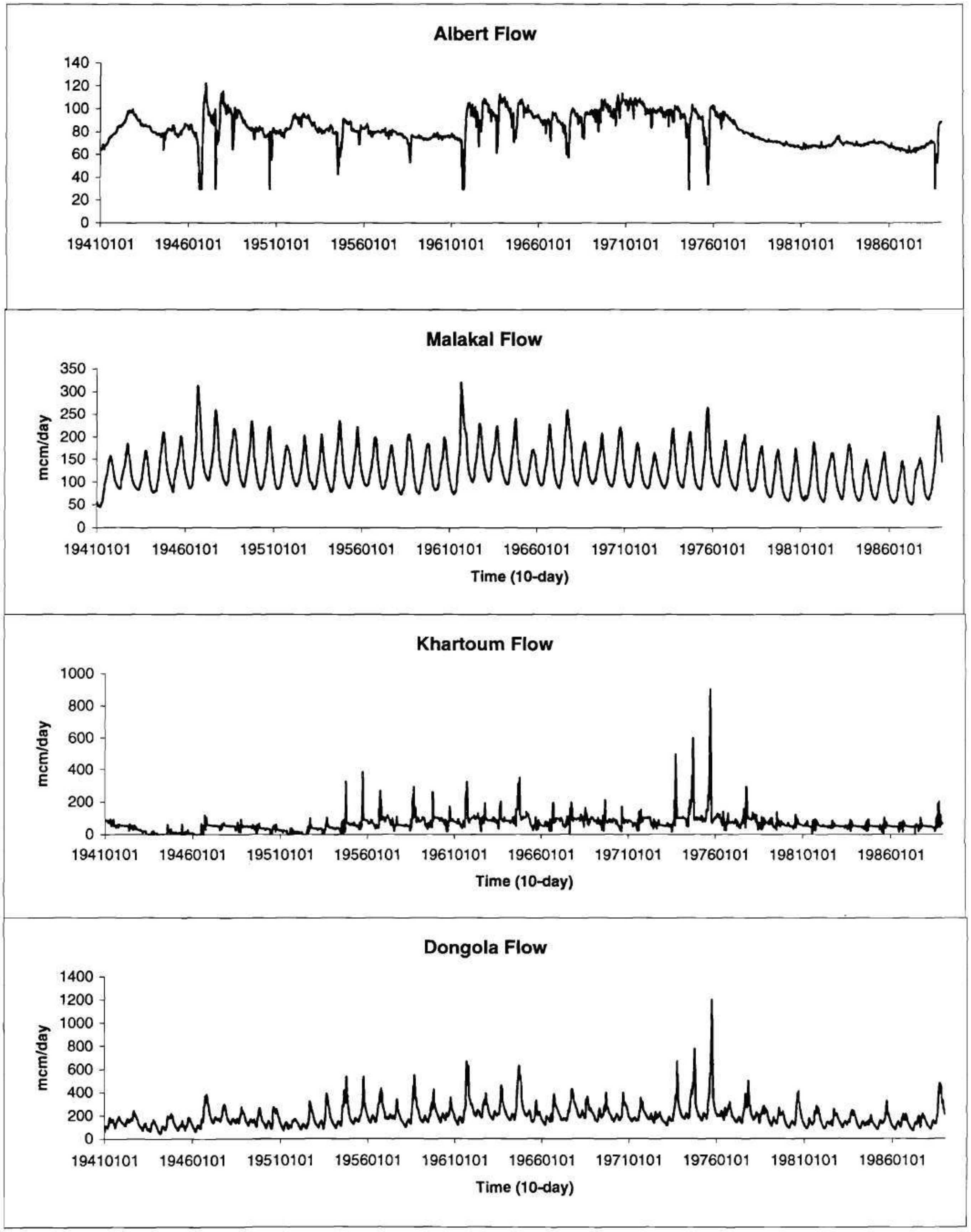


Figure 3.5: Simulated Flow Sequences; Scenario IV; Current Demand; Baseline

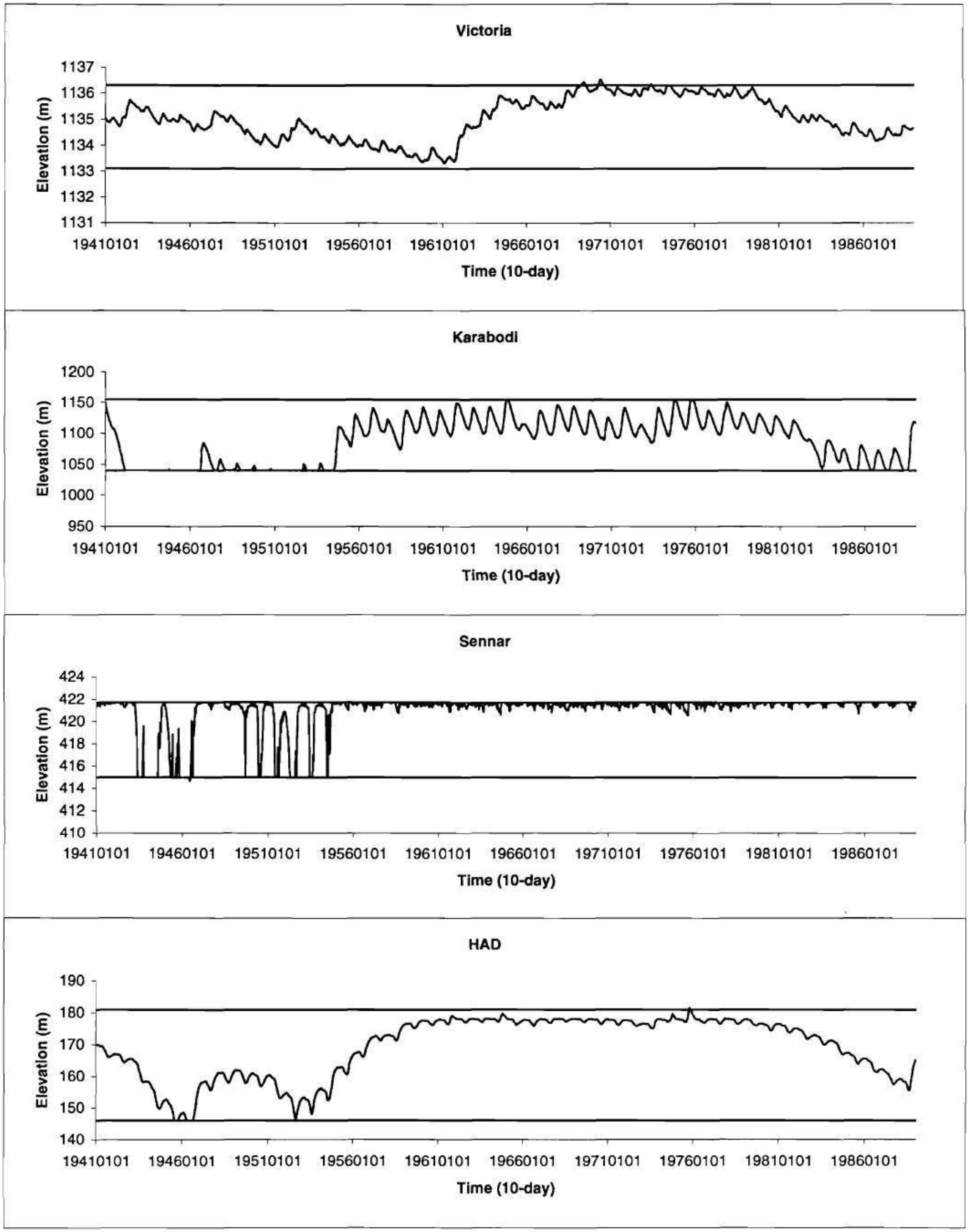


Figure B.3.6: Simulated Elevation Sequences for Selected Reservoirs; Scenario IV; Current Demand; Baseline

Table B.3.1: Nile Basin Assessment: White Nile Statistics (Baseline)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	Inflow (bcm)	13.31	13.31	13.31	13.31	13.31	13.31	13.31	13.31	13.31	13.31	13.31	13.31
	Net Evp. (bcm)	-13.01	-12.95	-12.90	-13.01	-12.95	-12.90	-13.16	-13.13	-13.11	-13.16	-13.13	-13.11
	Withdrawal (bcm)	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00
	Outflow (bcm)	27.35	25.09	22.84	27.35	25.09	22.84	26.97	24.56	22.16	26.97	24.56	22.17
Kyoga	Inflow (bcm)	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20	4.20
	Net Evp. (bcm)	1.62	1.60	1.57	1.62	1.60	1.57	1.65	1.62	1.59	1.65	1.62	1.59
	Outflow (bcm)	29.87	27.65	25.44	29.87	27.65	25.44	29.46	27.09	24.73	29.46	27.09	24.73
Albert	Inflow (bcm)	4.21	4.21	4.21	4.21	4.21	4.21	4.21	4.21	4.21	4.21	4.21	4.21
	Net Evp. (bcm)	3.18	3.16	3.15	3.18	3.16	3.15	3.20	3.18	3.17	3.20	3.18	3.17
	Outflow (bcm)	30.79	28.59	26.42	30.79	28.59	26.42	30.33	27.99	25.67	30.32	27.99	25.67
Torrents	Inflow (bcm)	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62	13.62
Mongala	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Flow (bcm)	44.41	41.21	38.04	44.41	41.21	38.04	43.94	40.61	37.29	43.94	40.61	37.29
Sudd	Loss (bcm)	25.10	22.82	20.69	25.10	22.82	20.69	14.55	12.91	11.64	14.52	12.93	11.63
Sobat	Inflow (bcm)	14.01	14.01	14.01	14.01	14.01	14.01	18.76	18.76	18.76	18.76	18.76	18.76
Malakal	Flow (bcm)	33.32	32.40	31.37	33.32	32.40	31.37	48.16	46.46	44.41	48.18	46.44	44.42
Melut	Flow (bcm)	33.16	32.27	31.27	33.16	32.27	31.27	47.47	45.83	43.85	47.50	45.81	43.86
Gebel El Aulia	Withdrawal (bcm)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	Net Evp.(bcm)	3.61	3.58	3.54	3.61	3.58	3.54	4.06	4.00	3.93	4.06	4.00	3.93
	Outflow (bcm)	28.05	27.20	26.24	28.05	27.20	26.24	41.92	40.34	38.43	41.95	40.32	38.44
Bl. Nile at Khrtm.	Flow (bcm)	26.96	23.28	21.52	25.50	15.72	8.66	26.97	23.28	21.56	25.97	16.36	8.52
Atbara River	Flow (bcm)	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28
HAD	Inflow (bcm)	60.51	55.91	53.14	59.14	48.37	40.21	74.71	69.38	65.71	73.84	62.47	52.62
	Evap.(bcm)	9.64	7.72	6.59	9.40	5.87	4.98	11.54	10.58	9.68	11.77	9.14	5.71
	Withdrawal (bcm)	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00
	Outflow (bcm)	50.78	46.05	44.00	50.12	40.75	33.28	62.19	55.71	52.84	61.82	51.46	44.78

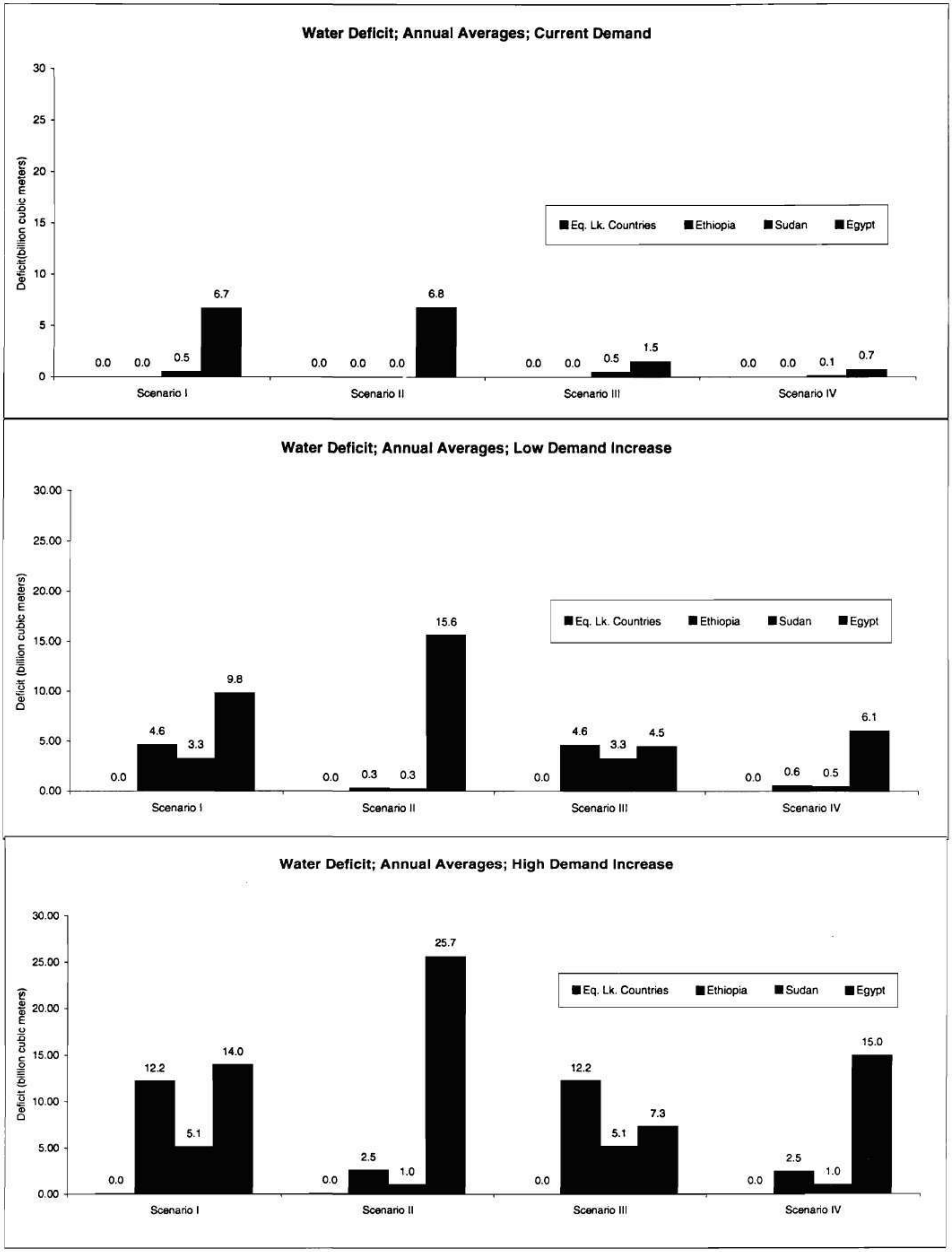
Table B.3.2: Nile Basin Assessment:Blue Nile Statistics (Baseline)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Lake Tana	Inflow (bcm)	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	3.61	3.12	2.93	3.60	2.64	2.05	3.61	3.12	2.93	3.61	2.71	2.03
Karadobi	Inflow (bcm)	13.49	13.49	13.49	13.49	13.49	13.49	13.49	13.49	13.49	13.49	13.49	13.49
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	17.09	15.80	15.11	16.96	15.18	14.03	17.09	15.80	15.11	17.20	15.43	13.99
Mabil	Inflow (bcm)	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65	7.65
	Withdrawal (bcm)	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00
	Outflow (bcm)	24.74	21.87	20.53	24.47	19.83	16.64	24.74	21.87	20.53	24.71	20.19	16.46
Mendaia	Inflow (bcm)	11.64	11.64	11.64	11.64	11.64	11.64	11.64	11.64	11.64	11.64	11.64	11.64
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	36.38	32.75	30.94	35.91	30.32	26.34	36.38	32.75	30.94	36.15	30.69	26.15
Border	Inflow (bcm)	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42	7.42
	Withdrawal (bcm)	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00
	Outflow (bcm)	43.81	38.29	35.87	43.04	33.67	26.74	43.81	38.29	35.87	43.27	34.13	26.57
Roseires	Inflow (bcm)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	Outflow (bcm)	42.94	37.60	35.24	41.97	32.76	26.01	42.94	37.57	35.24	42.29	33.25	25.82
Sennar	Inflow (bcm)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Withdrawal (bcm)	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62
	Outflow (bcm)	26.68	22.88	21.08	25.18	15.09	7.82	26.69	22.89	21.11	25.66	15.75	7.67
Dinder+Rahad	Inflow (bcm)	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
Bl. Nile at Khrtm.	Flow (bcm)	26.96	23.28	21.52	25.50	15.72	8.66	26.97	23.28	21.56	25.97	16.36	8.52
K. Girba	Inflow (bcm)	9.95	9.95	9.95	9.95	9.95	9.95	9.95	9.95	9.95	9.95	9.95	9.95
	Withdrawal (bcm)	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
	Outflow (bcm)	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28	8.28

Appendix C

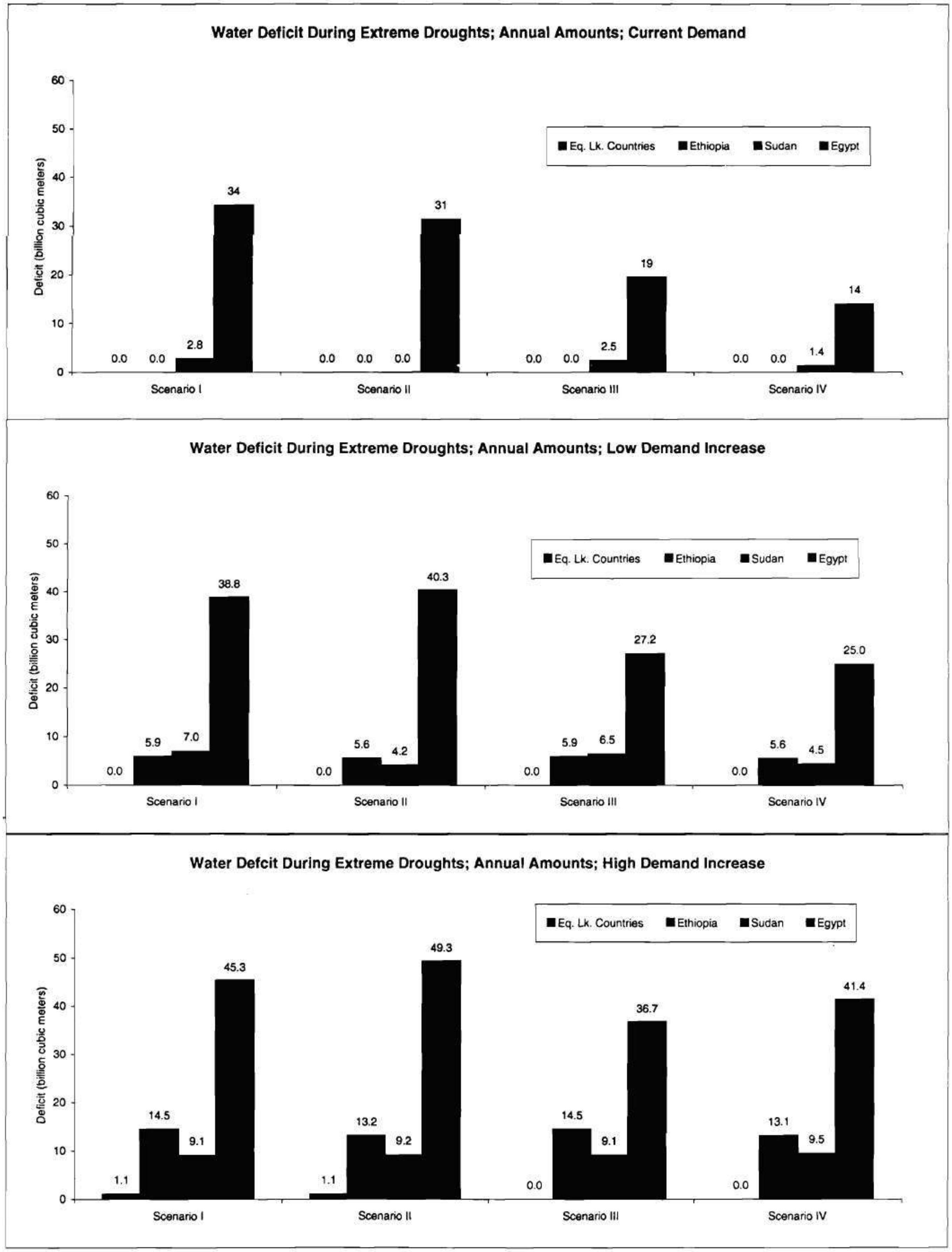
"2020" Climate Assessment Results

The figures and tables included in this appendix follow the same format as those of Appendix B. As a general comment, the "2020" climate scenario is similar to the baseline. As a result, the basin response under this scenario is also similar to that of the baseline.



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure C.1.1: Deficit; Annual Average; 2020 Scenario



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure C.1.2: Deficit During Extreme Droughts; Annual Amounts; 2020 Scenario

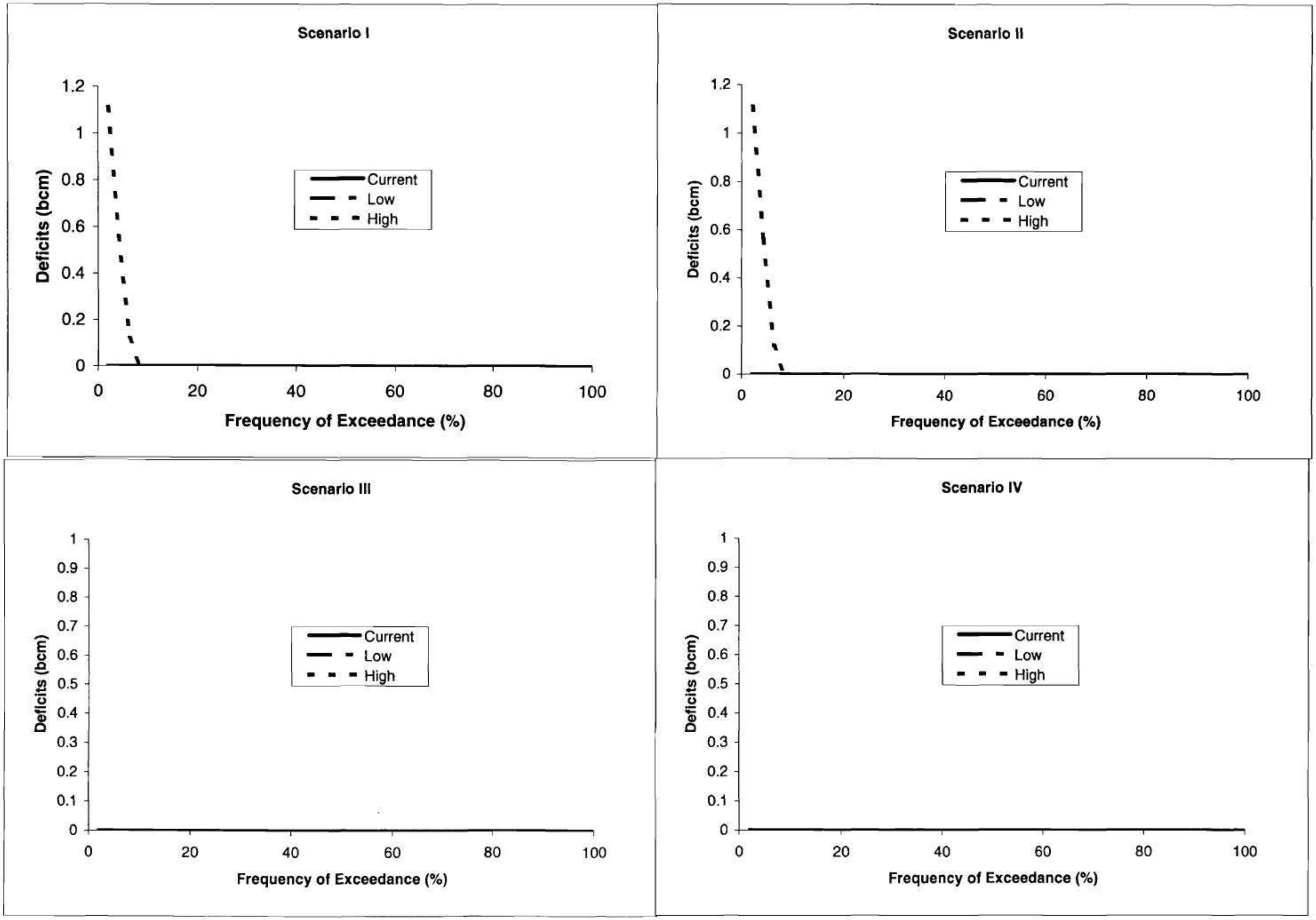


Figure C.1.3a: Annual Deficit Frequency Curves; Equatorial Lake Region; 2020 Scenario

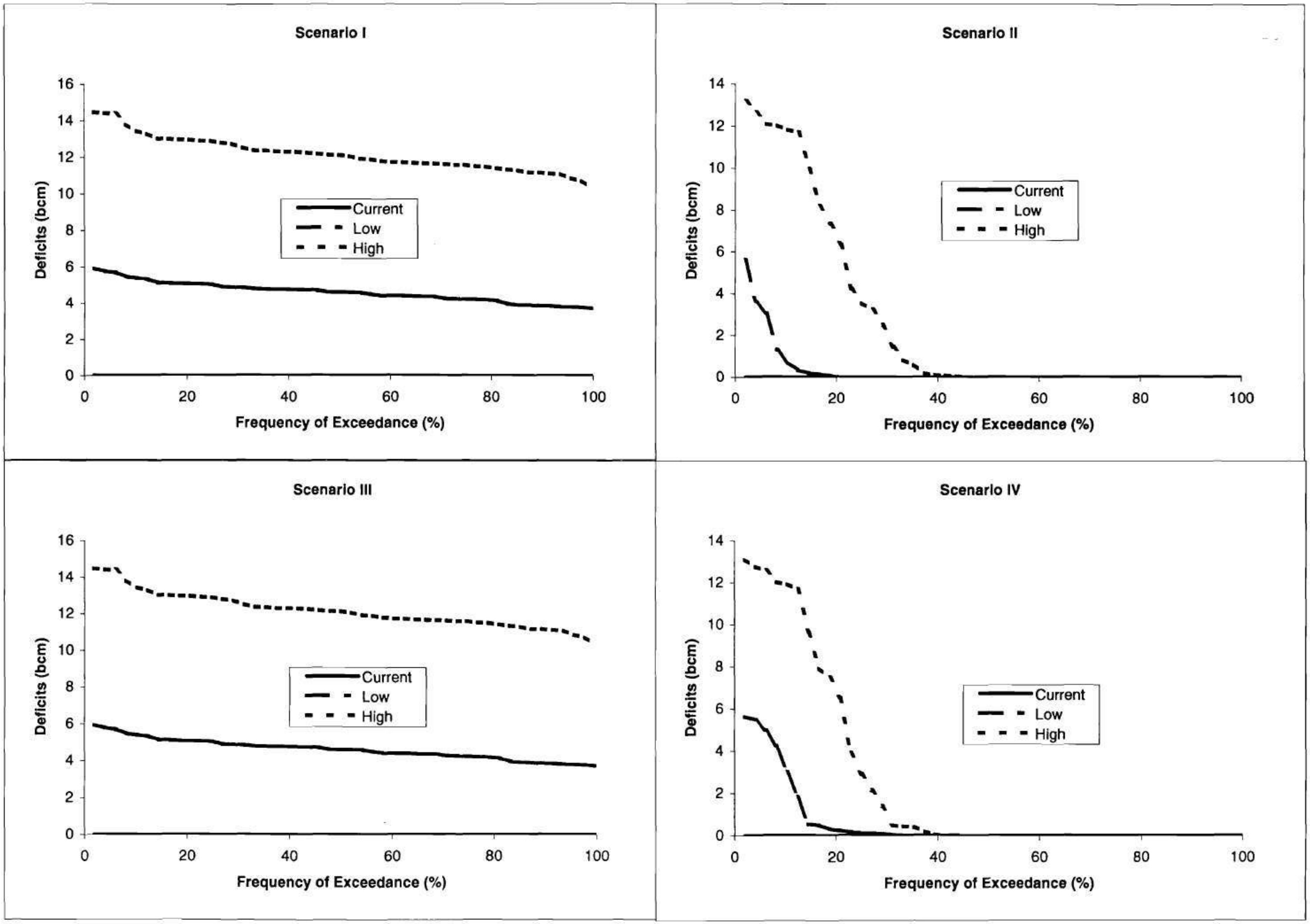


Figure C.1.3b: Annual Deficit Frequency Curves; Ethiopia/Eritrea; 2020 Scenario

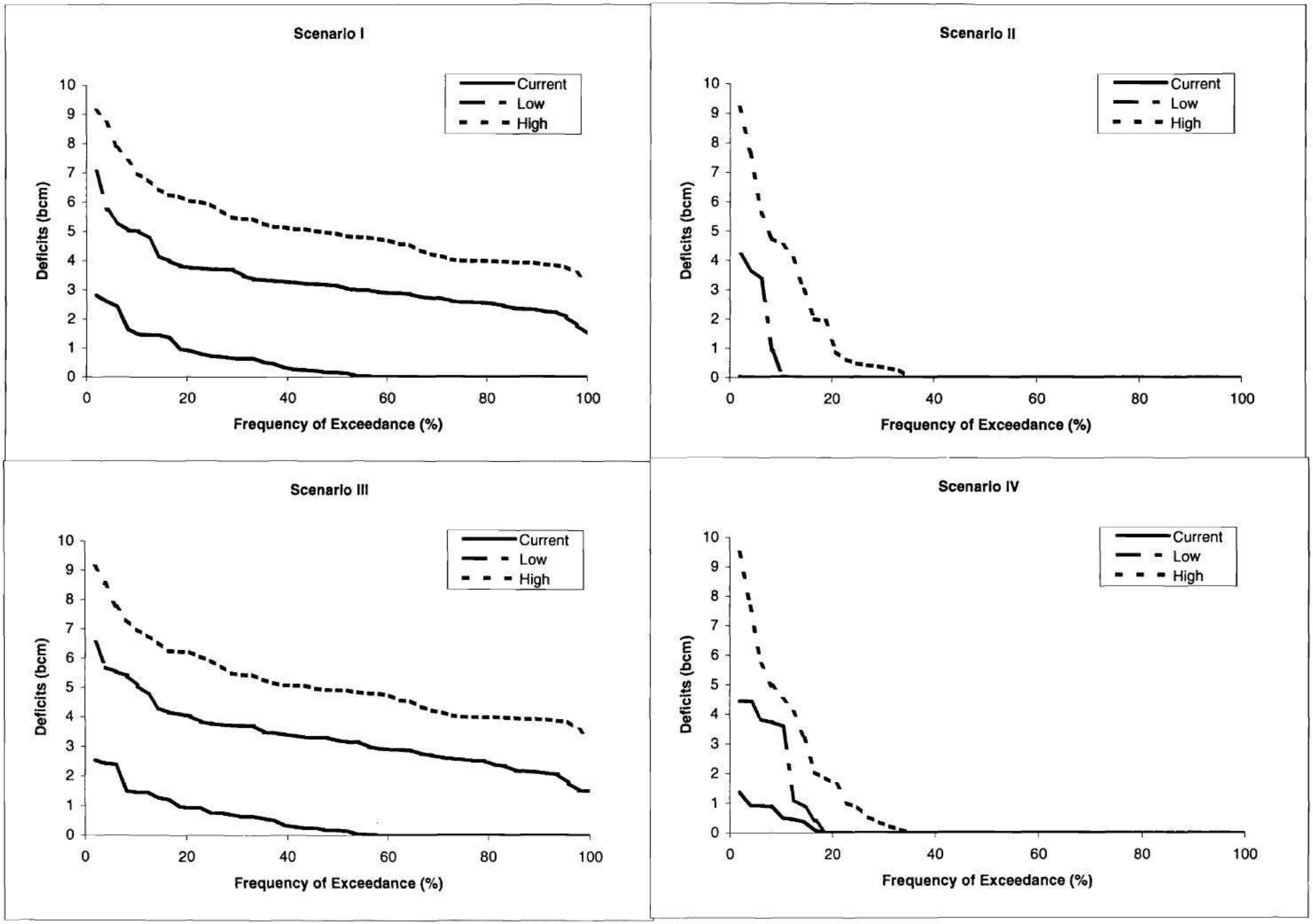


Figure C.1.3c: Annual Deficit Frequency Curves; Sudan; 2020 Scenario

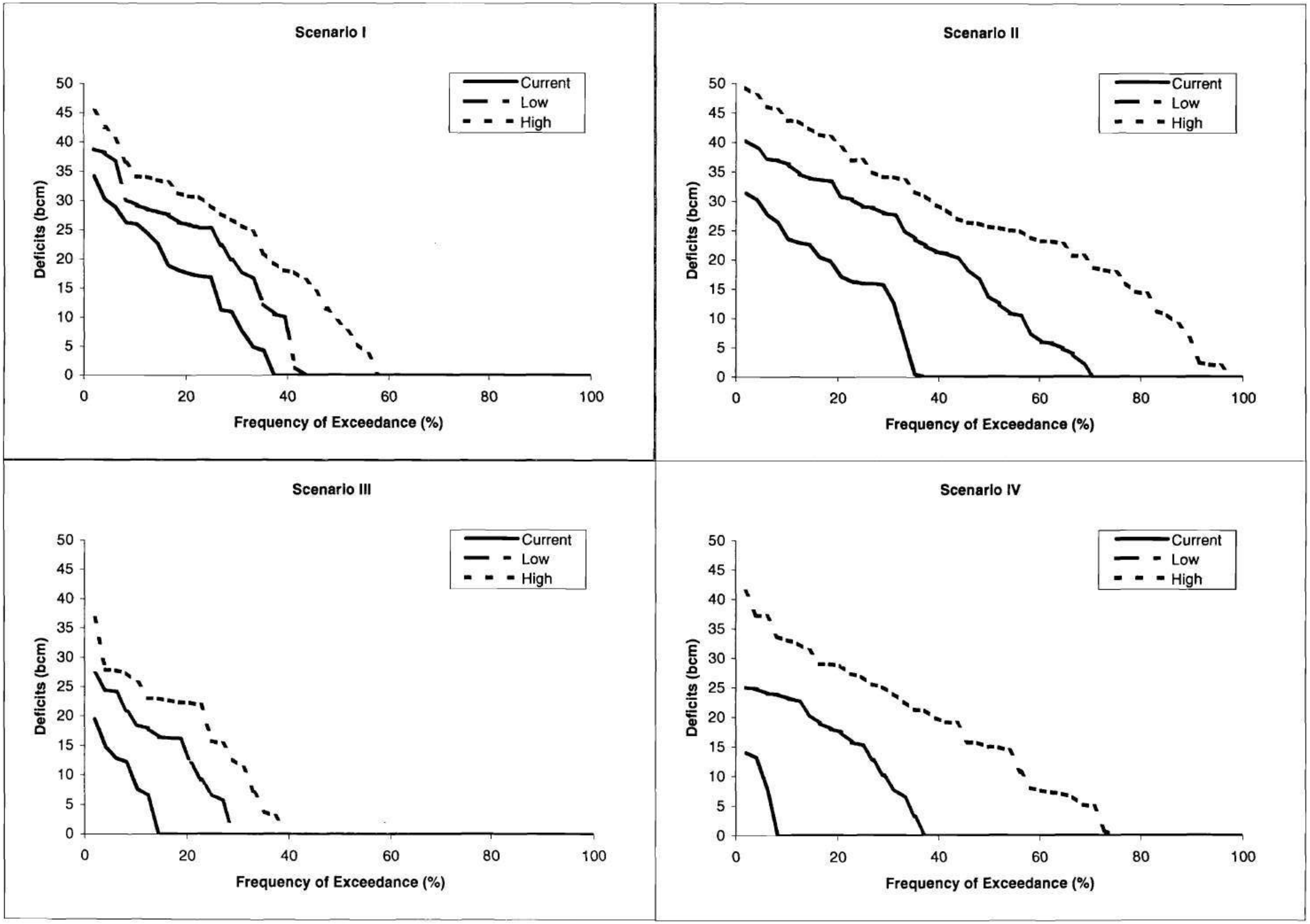
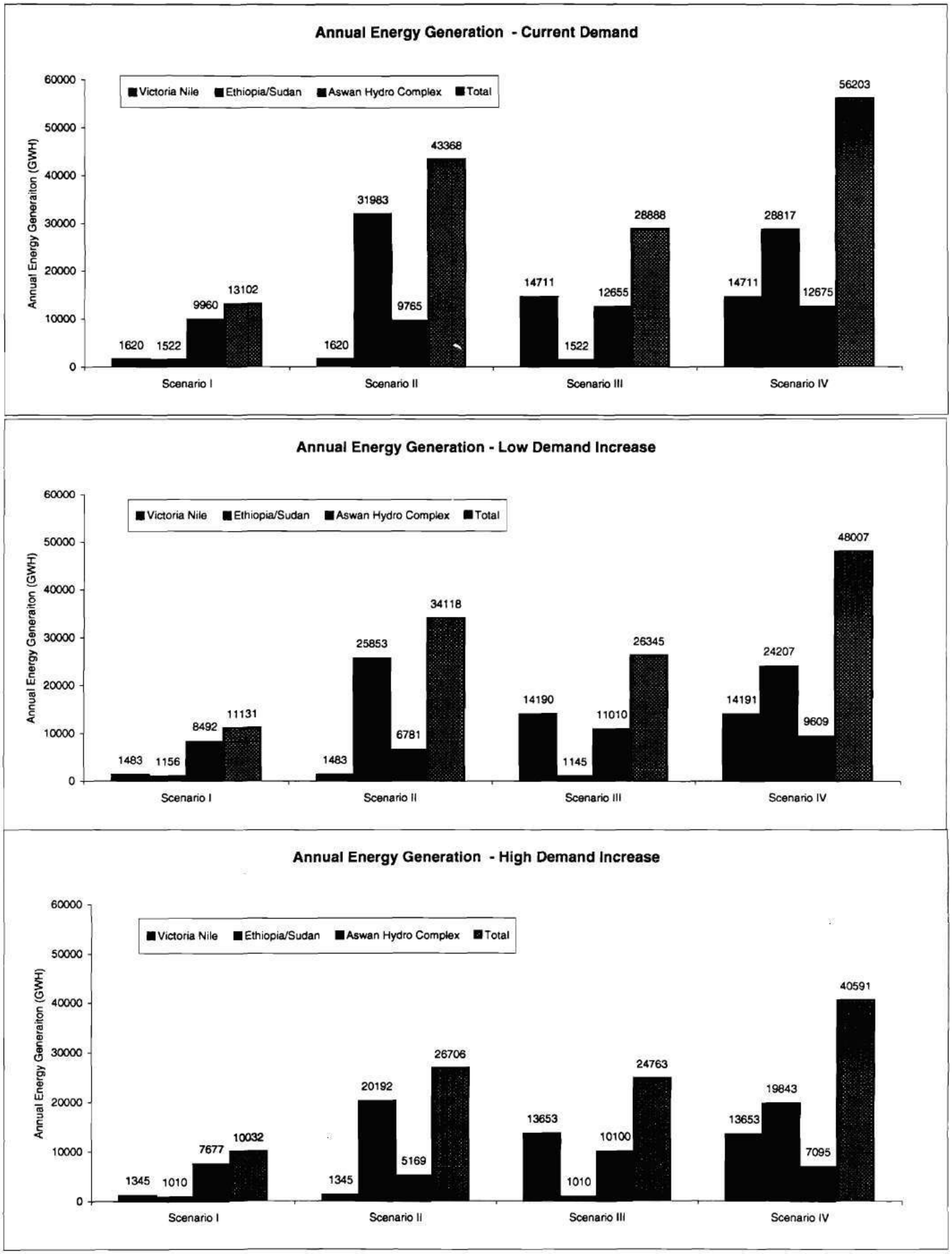


Figure C.1.3d: Annual Deficit Frequency Curves; Egypt; 2020 Scenario

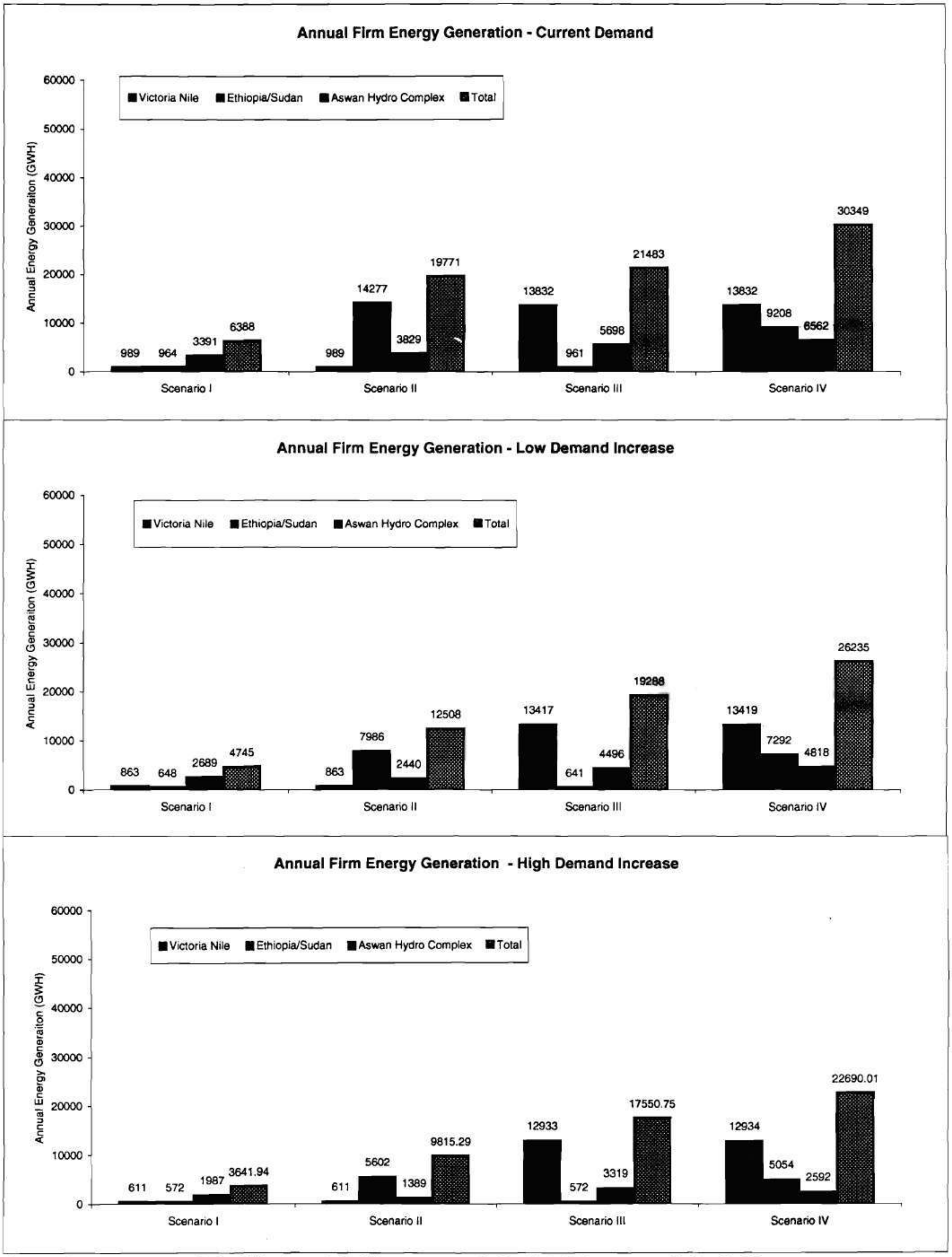
Table C.1: Nile Basin Assessment: Annual Average Deficit Statistics (2020 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	0.00	0.00	0.04	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Mongala	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gabel Aulia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tana	0.00	0.52	1.33	0.00	0.01	0.21	0.00	0.52	1.33	0.00	0.04	0.21
Karadobi	0.00	0.22	0.73	0.00	0.02	0.19	0.00	0.22	0.73	0.00	0.04	0.20
Mabil	0.00	1.45	3.80	0.00	0.11	0.91	0.00	1.45	3.80	0.00	0.20	0.79
Mendaia	0.00	0.25	0.80	0.00	0.03	0.21	0.00	0.25	0.80	0.00	0.05	0.21
Border	0.00	2.16	5.52	0.00	0.15	1.03	0.00	2.16	5.52	0.00	0.25	1.04
Sennar	0.49	3.27	5.13	0.00	0.25	0.96	0.48	3.29	5.13	0.12	0.47	1.00
Girba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HAD Upstream	0.00	0.02	0.05	0.00	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00
HAD Downstream	6.67	9.79	13.93	6.79	15.58	25.59	1.53	4.49	7.28	0.74	6.05	15.00



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure C.2.1: Annual Average Energy Generation; 2020 Scenario



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure C.2.2: Annual Firm Energy Generation; 2020 Scenario

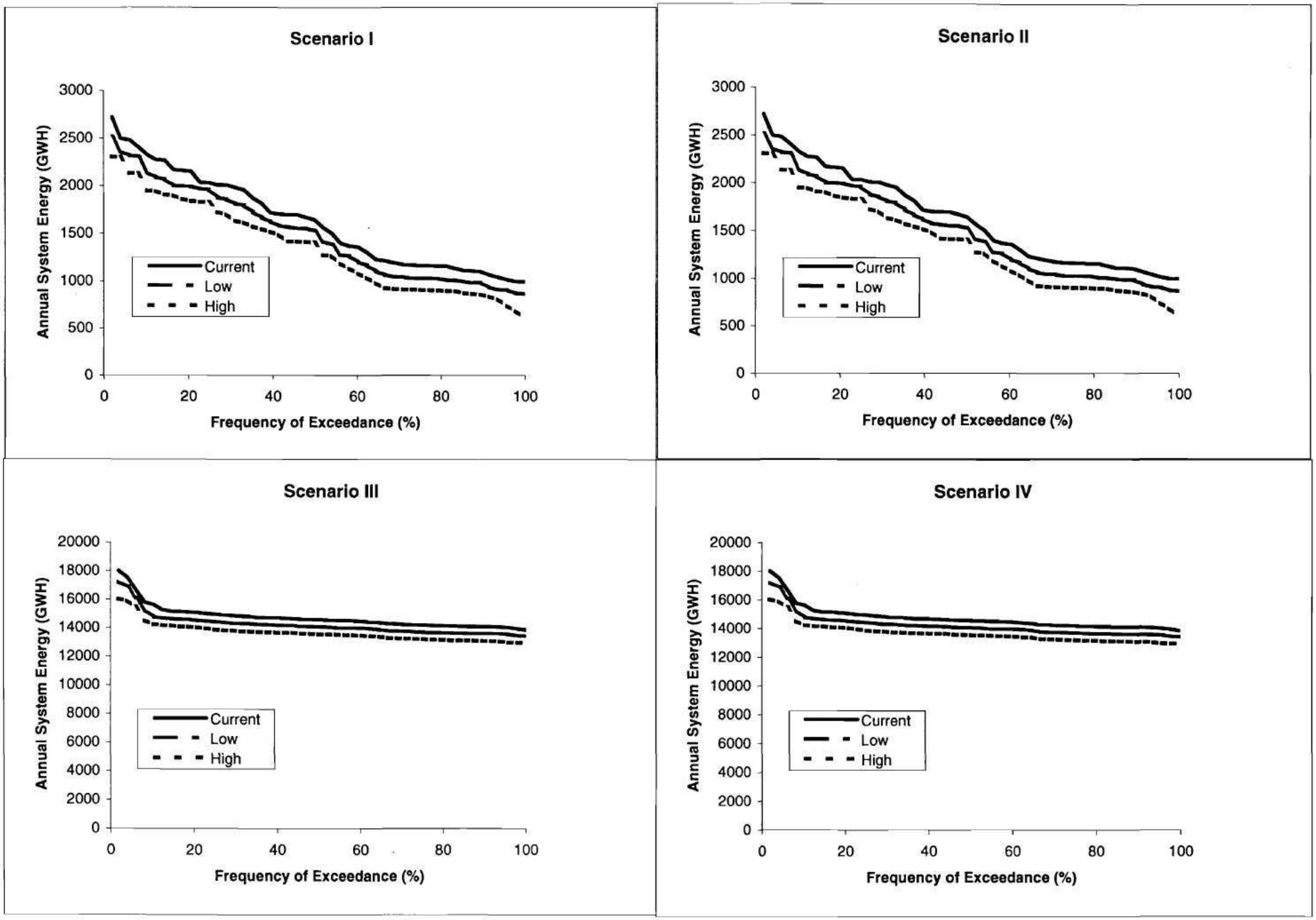


Figure C.2.3a: Annual Energy Frequency Curves; Victoria Nile; 2020 Scenario

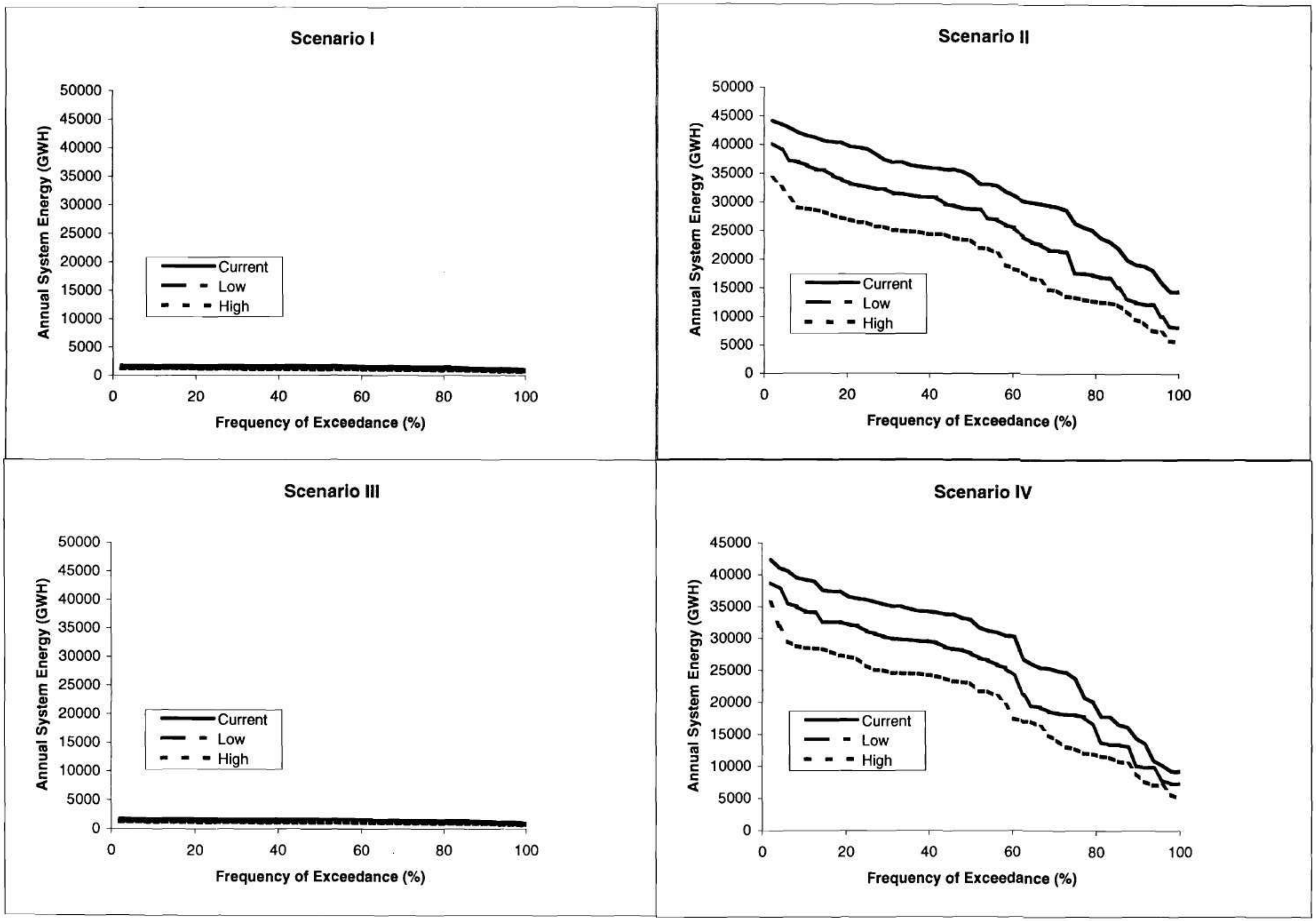


Figure C.2.3b: Annual Energy Frequency Curves; Ethiopia/Sudan; 2020 Scenario

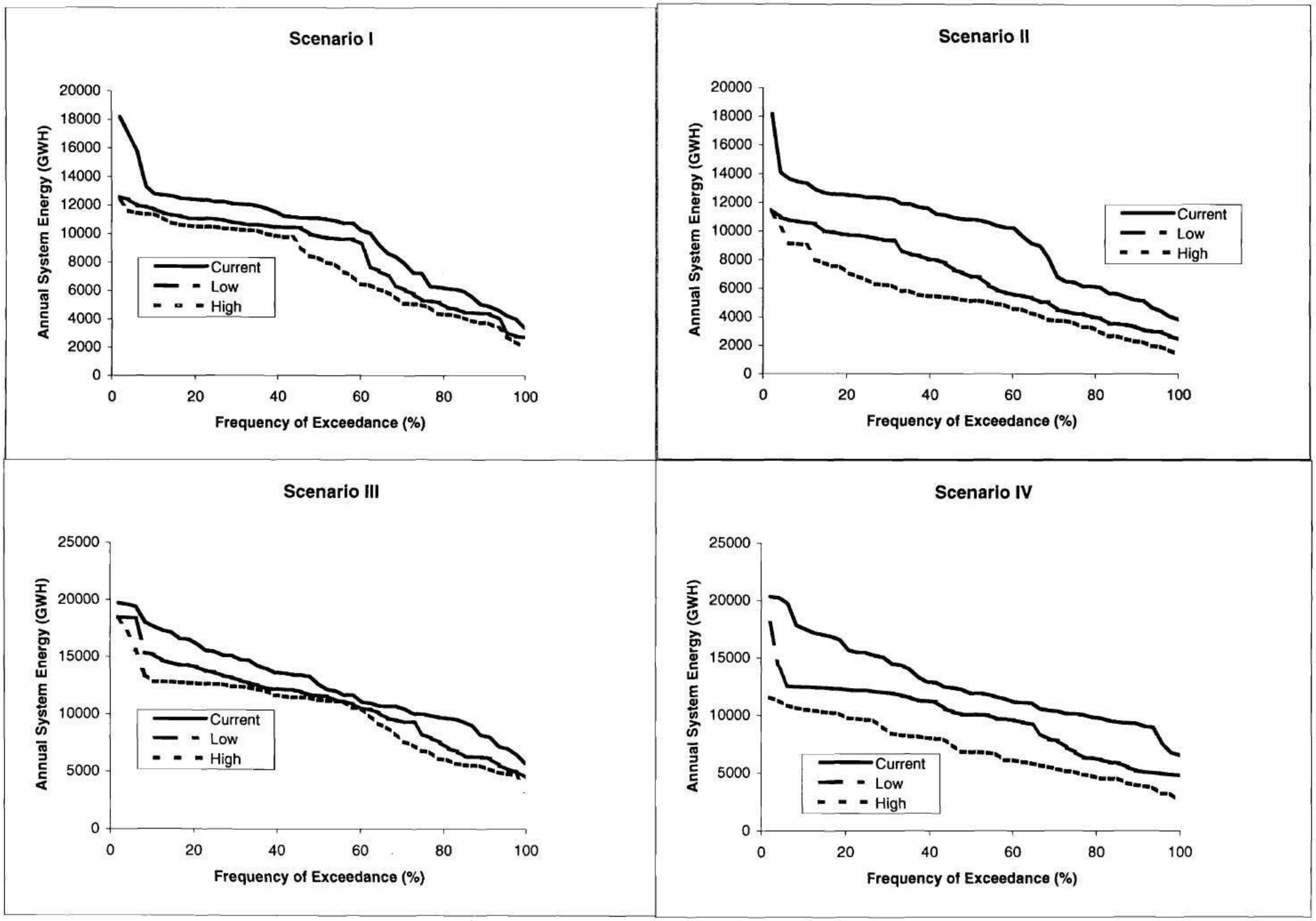


Figure C.2.3c: Annual Energy Frequency Curves; HAD Hydro Complex; 2020 Scenario

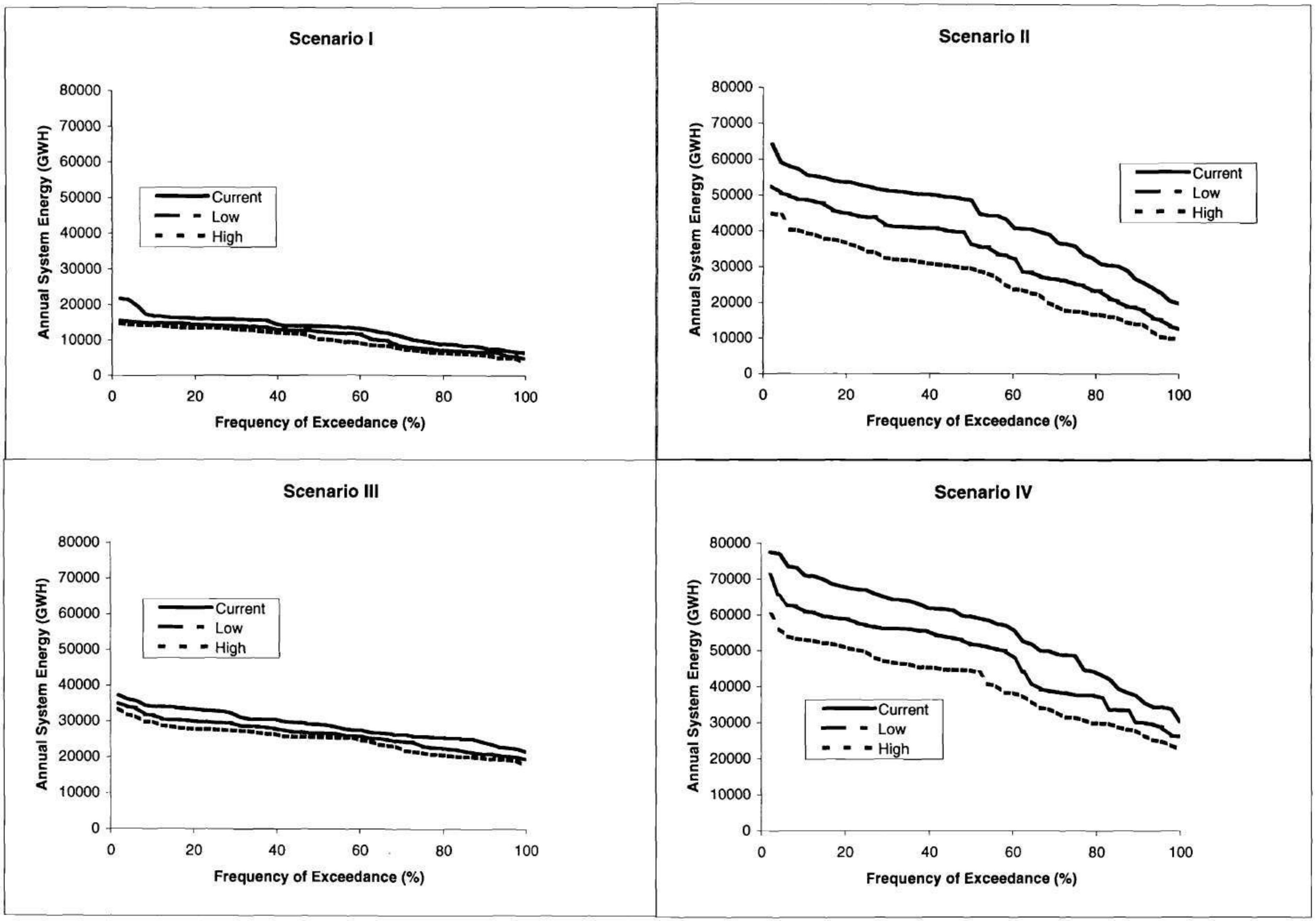


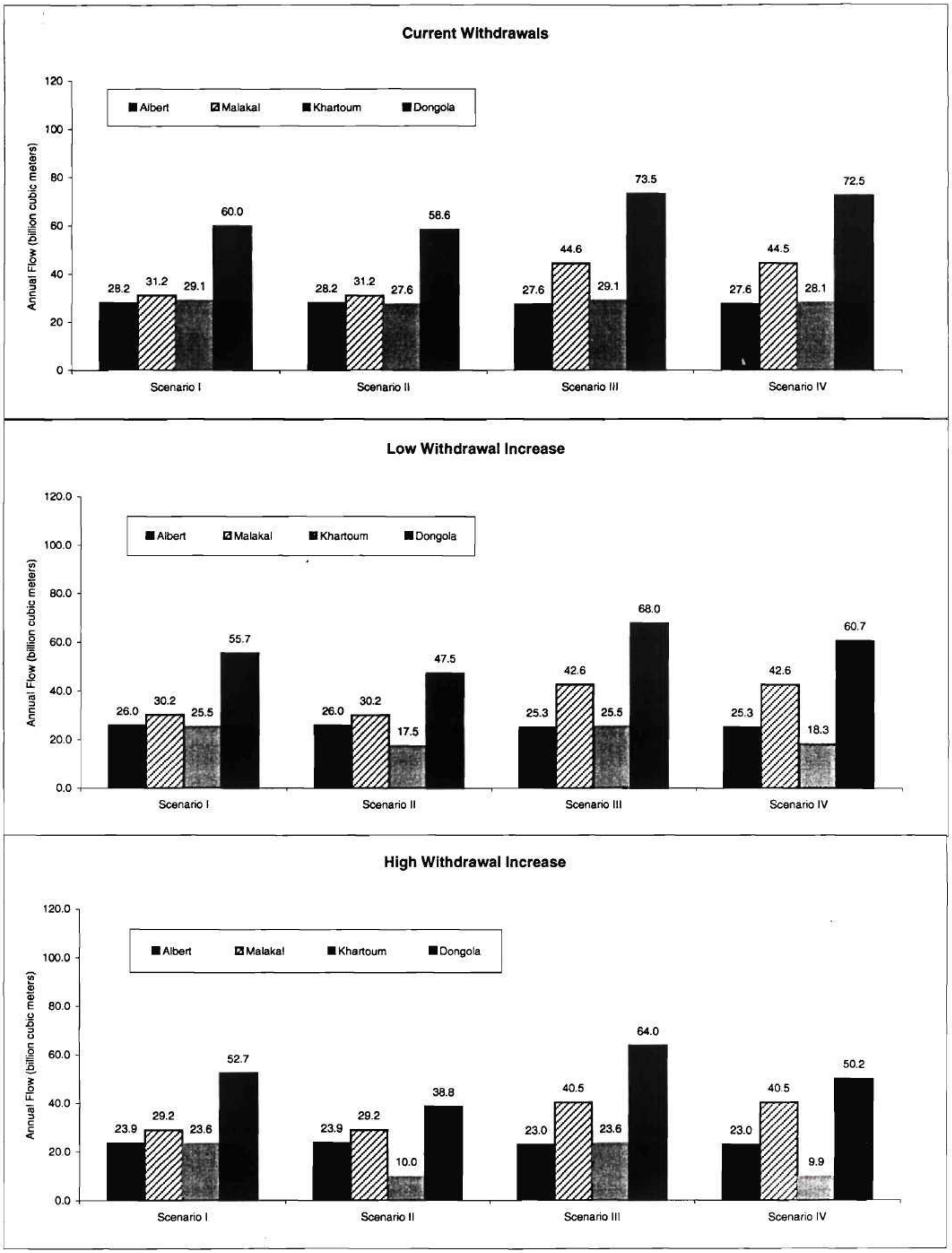
Figure C.2.3d: Annual Energy Frequency Curves; Total System; 2020 Scenario

Table C.2.1: Nile Basin Assessment: Average Annual Energy (GWH) Statistics (2020 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Owen Falls	1620	1483	1345	1620	1483	1345	1640	1497	1354	1640	1497	1355
Bujagali	0	0	0	0	0	0	1437	1310	1184	1437	1310	1184
Kalagala	0	0	0	0	0	0	1755	1599	1444	1755	1599	1444
Kamdini	0	0	0	0	0	0	1516	1420	1310	1516	1421	1310
Ayago South	0	0	0	0	0	0	2665	2665	2663	2665	2665	2663
Ayago North	0	0	0	0	0	0	2051	2051	2051	2051	2051	2051
Murchison	0	0	0	0	0	0	3647	3647	3647	3647	3647	3647
Subtotal	1620	1483	1345	1620	1483	1345	14711	14190	13653	14711	14191	13653
Lake Tana	0	0	0	1530	1267	1022	0	0	0	1514	1269	1006
Karadobi	0	0	0	6296	4927	3282	0	0	0	3682	3168	2705
Mabil	0	0	0	5707	4367	3090	0	0	0	4877	4036	3247
Mendaia	0	0	0	9521	8092	6996	0	0	0	9630	8222	6941
Border	0	0	0	6830	5328	4193	0	0	0	6906	5469	4212
Subtotal	0	0	0	29883	23980	18584	0	0	0	26609	22164	18110
Roseires	1369	1056	926	1929	1708	1458	1368	1045	926	2041	1882	1584
Sennar	114	60	44	131	126	110	114	60	45	127	121	110
K. Girba	39	39	40	39	39	39	40	39	39	39	39	39
Subtotal	1522	1156	1010	2100	1873	1607	1522	1145	1010	2208	2043	1733
HAD (GWH)	9960	8492	7677	9765	6781	5169	12655	11010	10100	12675	9609	7095
Total	**13101**	**11131**	**10032**	**43368**	**34118**	**26706**	**28888**	**26345**	**24763**	**56203**	**48007**	**40591**

Table C.2.2: Nile Basin Assessment: Annual Firm Energy (GWH) Statistics (2020 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Owen Falls	989	863	611	989	863	611	1320	1194	1068	1320	1194	1068
Bujagali	0	0	0	0	0	0	1164	1055	945	1165	1055	945
Kalagala	0	0	0	0	0	0	1418	1284	1150	1418	1285	1151
Kamdini	0	0	0	0	0	0	1374	1255	1134	1376	1255	1135
Ayago South	0	0	0	0	0	0	2663	2663	2608	2663	2663	2609
Ayago North	0	0	0	0	0	0	2050	2050	2050	2050	2050	2050
Murchison	0	0	0	0	0	0	3644	3644	3644	3644	3644	3644
Subtotal	989	863	611	989	863	611	13633	13145	12600	13635	13147	12602
Lake Tana	0	0	0	723	525	475	0	0	0	722	563	374
Karadobi	0	0	0	469	57	0	0	0	0	0	0	0
Mabil	0	0	0	2654	93	74	0	0	0	0	0	0
Mendaia	0	0	0	4846	3267	2197	0	0	0	3666	3257	2105
Border	0	0	0	3438	2183	1460	0	0	0	2743	2042	1414
Subtotal	0	0	0	12129	6125	4205	0	0	0	7131	5862	3893
Roseires	876	605	538	1552	761	537	875	597	538	1071	774	520
Sennar	57	12	3	131	46	14	56	13	3	74	38	13
K. Girba	10	13	15	13	13	14	13	13	13	16	16	12
Subtotal	943	630	556	1696	820	565	944	623	554	1161	827	545
HAD (GWH)	3391	2689	1987	3829	2440	1389	5698	4496	3319	6562	4818	2592
Total	**5323**	**4182**	**3155**	**18643**	**10249**	**6770**	**20274**	**18265**	**16473**	**28489**	**24655**	**19632**



S1: Current System   S2: S1+Full Development in Blue Nile   S3: S1 + Wetland Projects   S4: S1 + S2 + S3

Figure C.3.1: Annual Average Flows at Representative Basin Locations; 2020 Scenario

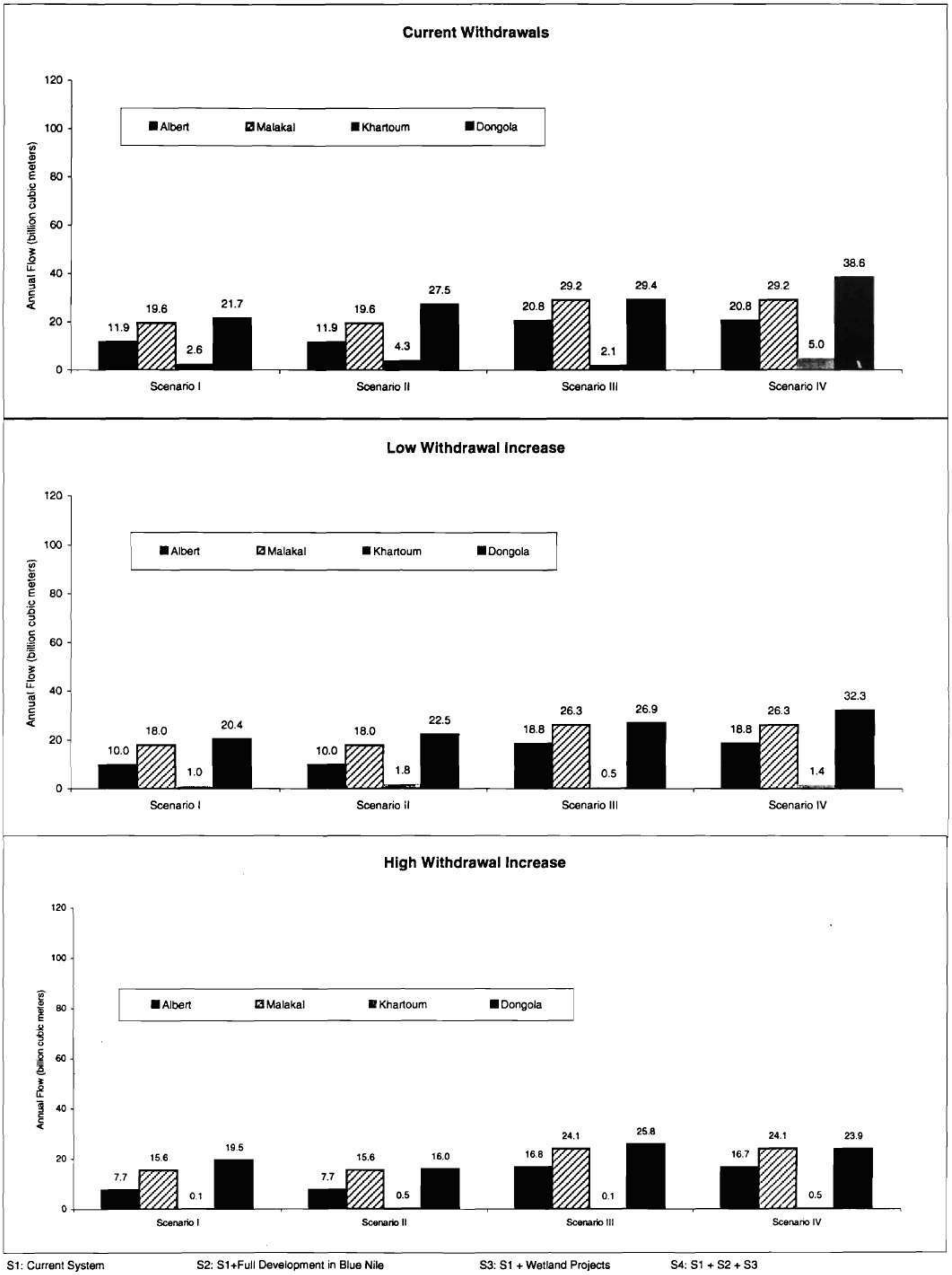
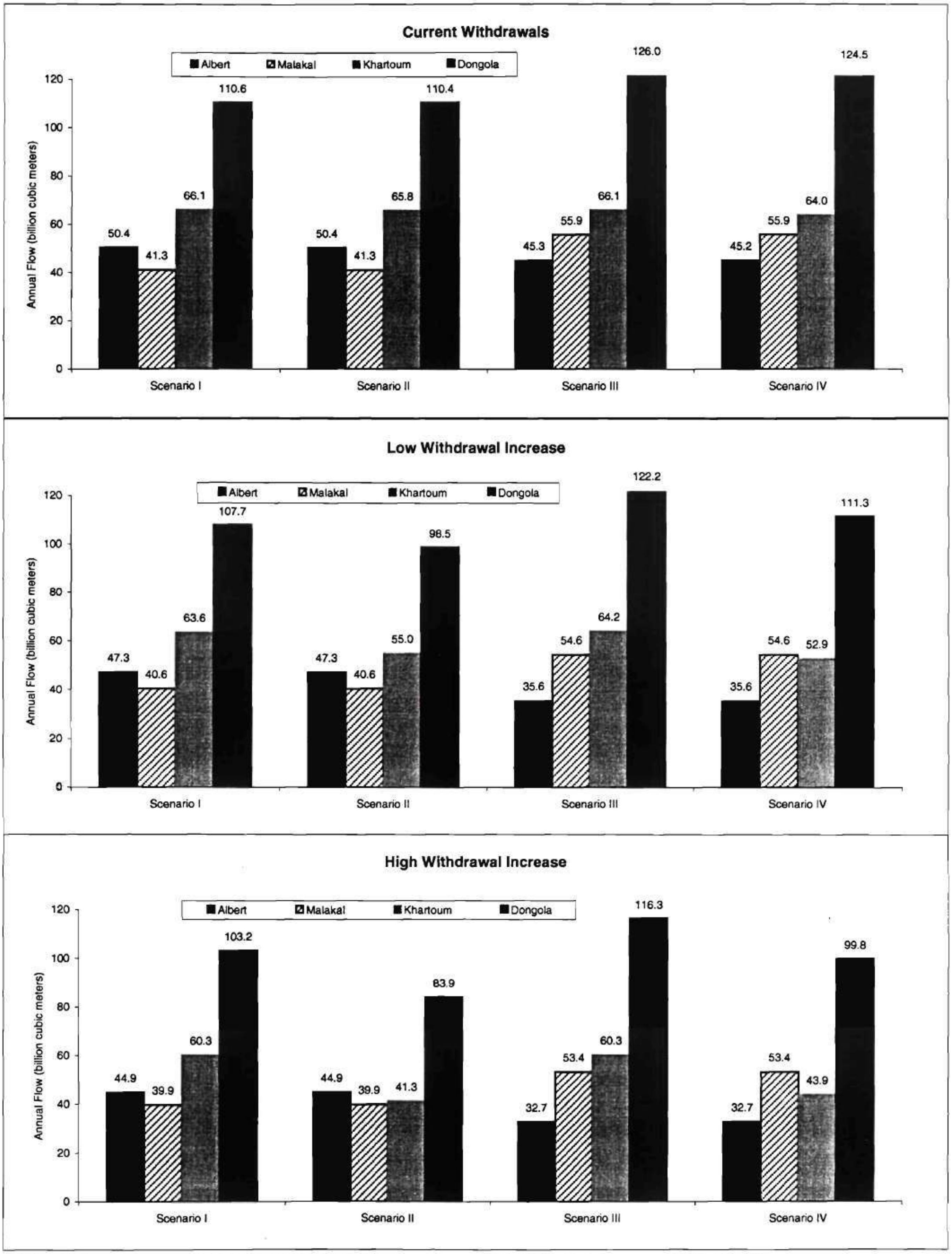


Figure C.3.2: Minimum Annual Flows at Representative Basin Locations; 2020 Scenario



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure C.3.3: Maximum Annual Flows at Representative Basin Locations; 2020 Scenario

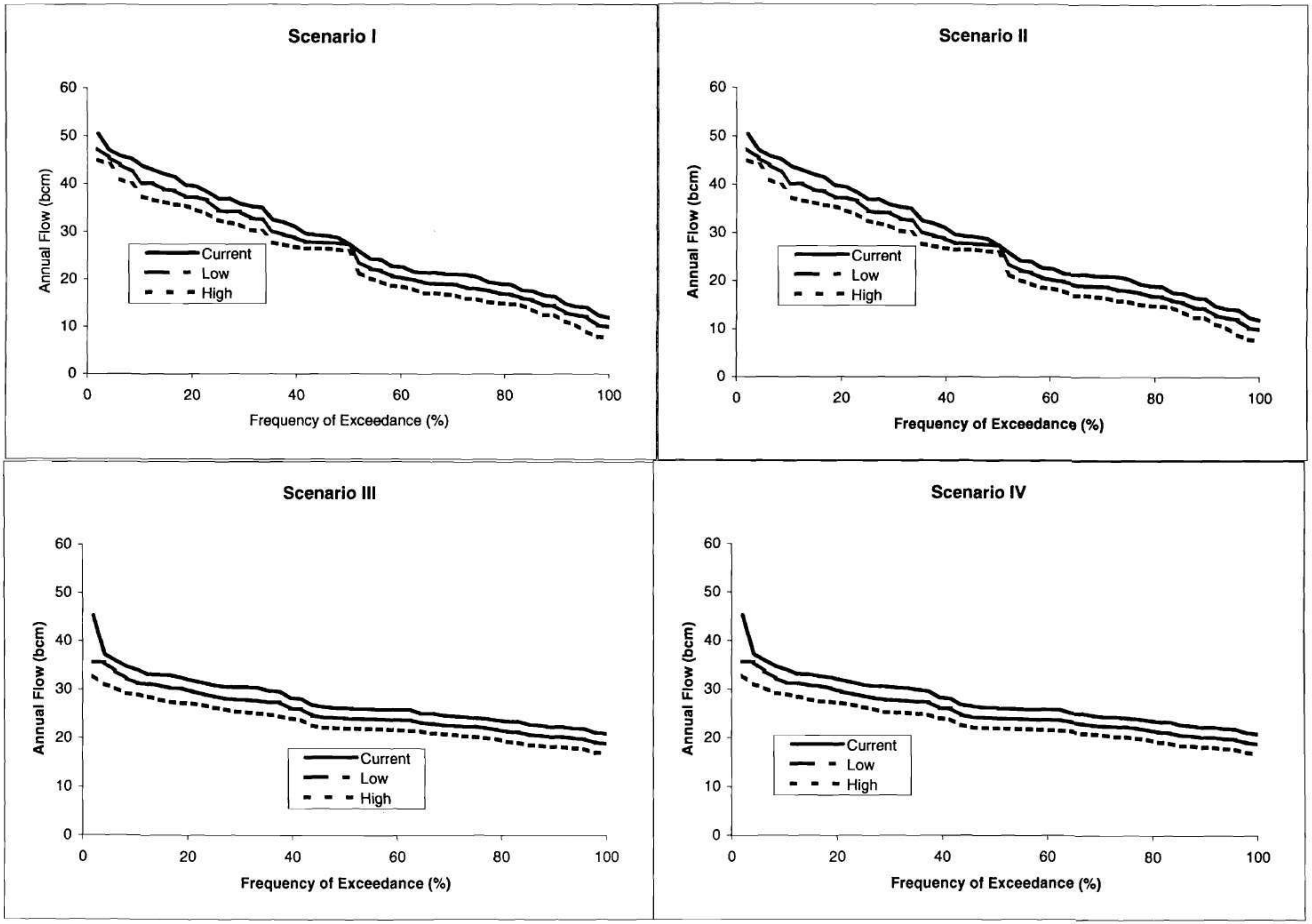


Figure C.3.4a: Flow Frequency Curves; Albert Outflows; 2020 Scenario

Table D.3.2: Nile Basin Assessment:Blue Nile Statistics (2050 Scenario)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Lake Tana	Inflow (bcm)	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	3.70	3.23	3.04	3.69	2.73	2.11	3.70	3.23	3.04	3.70	2.80	2.10
Karadobi	Inflow (bcm)	13.83	13.83	13.83	13.83	13.83	13.83	13.83	13.83	13.83	13.83	13.83	13.83
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	17.52	16.28	15.62	17.40	15.60	14.40	17.52	16.28	15.62	17.64	15.85	14.36
Mabil	Inflow (bcm)	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85	7.85
	Withdrawal (bcm)	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00
	Outflow (bcm)	25.37	22.60	21.31	25.10	20.43	17.12	25.37	22.60	21.31	25.34	20.77	16.96
Mendaia	Inflow (bcm)	11.94	11.94	11.94	11.94	11.94	11.94	11.94	11.94	11.94	11.94	11.94	11.94
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	37.31	33.80	32.05	36.83	31.20	27.09	37.31	33.80	32.05	37.07	31.56	26.93
Border	Inflow (bcm)	7.61	7.61	7.61	7.61	7.61	7.61	7.61	7.61	7.61	7.61	7.61	7.61
	Withdrawal (bcm)	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00
	Outflow (bcm)	44.92	39.60	37.26	44.15	34.71	27.56	44.92	39.60	37.26	44.38	35.14	27.40
Roseires	Inflow (bcm)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Outflow (bcm)	44.05	38.87	36.61	43.07	33.77	26.81	44.05	38.87	36.61	43.38	34.25	26.63
Sennar	Inflow (bcm)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Withdrawal (bcm)	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62
	Outflow (bcm)	27.84	24.27	22.43	26.24	15.96	8.44	27.84	24.31	22.44	26.70	16.64	8.31
Dinder+Rahad	Inflow (bcm)	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Bl. Nile at Khrtm.	Flow (bcm)	27.83	24.37	22.58	26.28	16.31	9.01	27.83	24.40	22.60	26.72	16.96	8.88
K. Girba	Inflow (bcm)	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51
	Withdrawal (bcm)	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
	Outflow (bcm)	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92

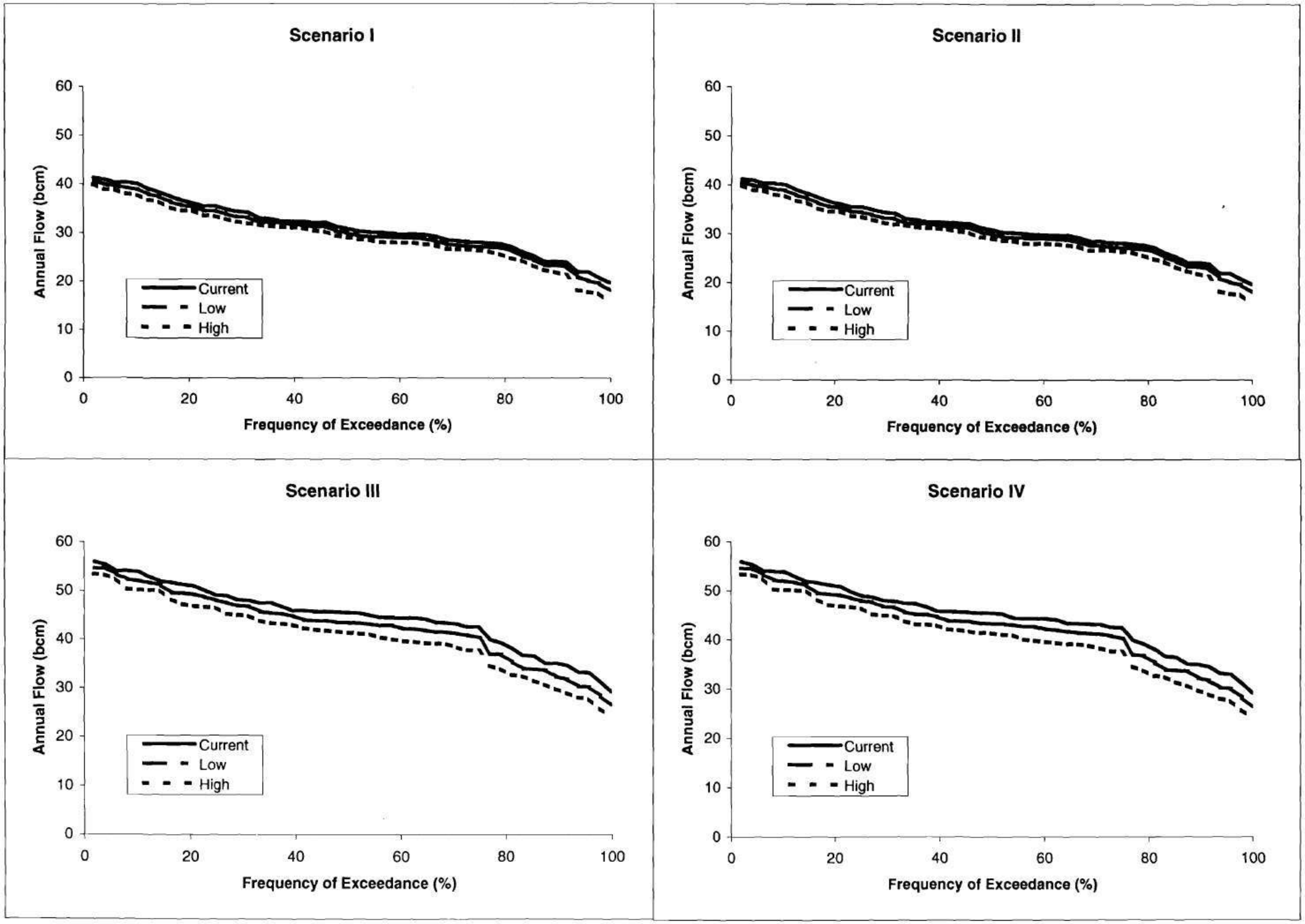


Figure C.3.4b: Flow Frequency Curves; Malakal flows; 2020 Scenario

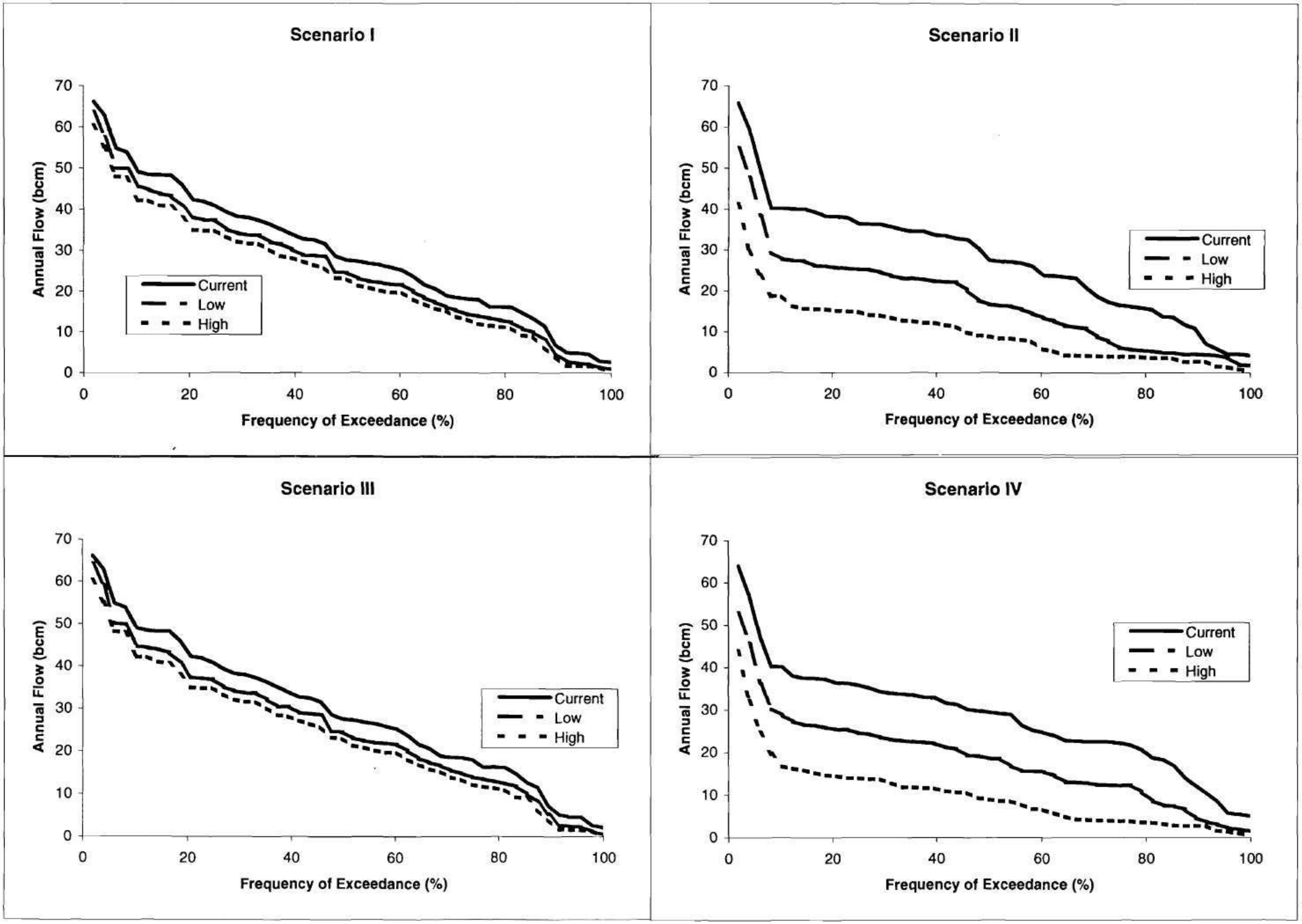


Figure C.3.4c: Flow Frequency Curves; Khartoum Flows; 2020 Scenario

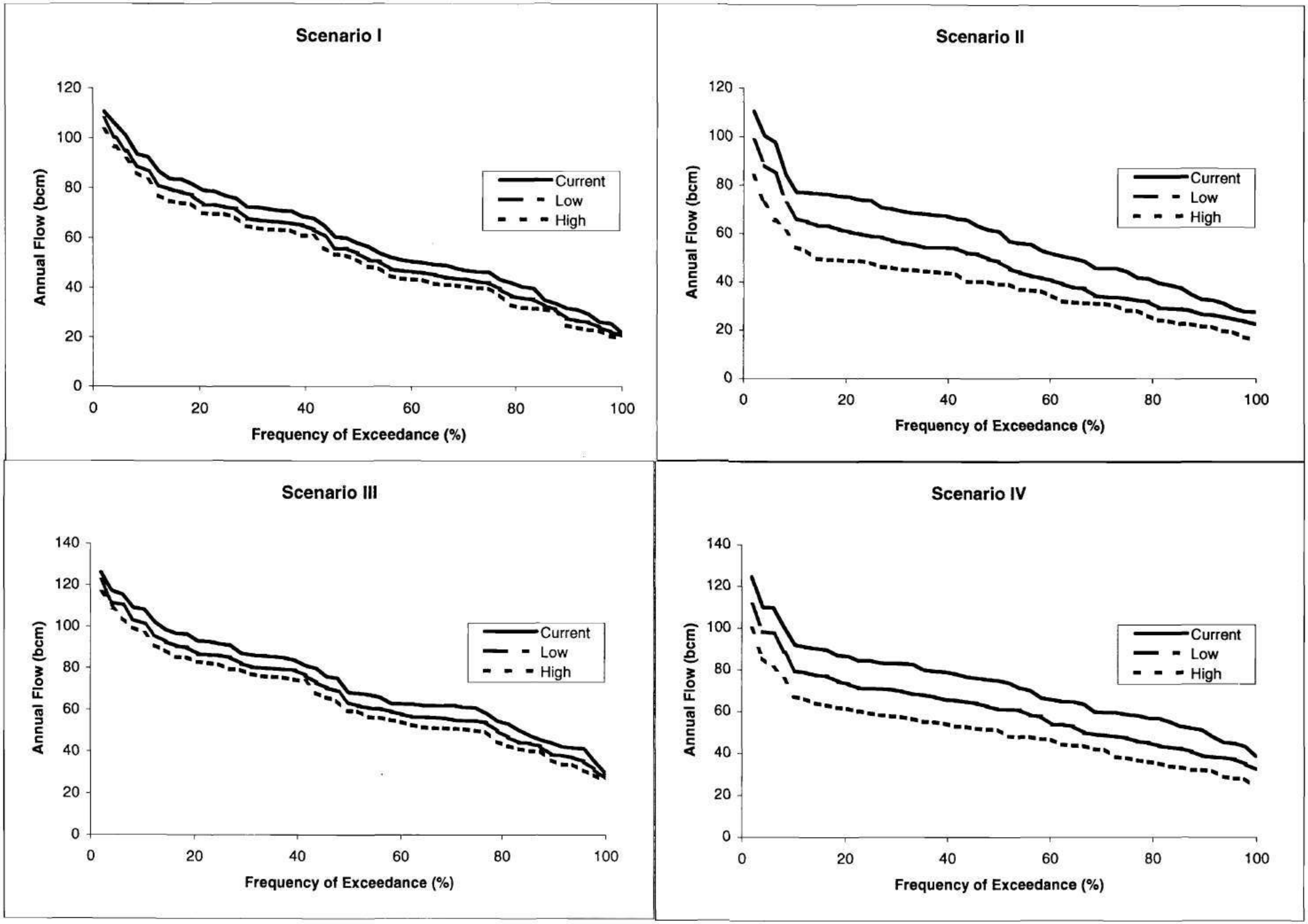


Figure C.3.4d: Flow Frequency Curves; Dongola Flows; 2020 Scenario

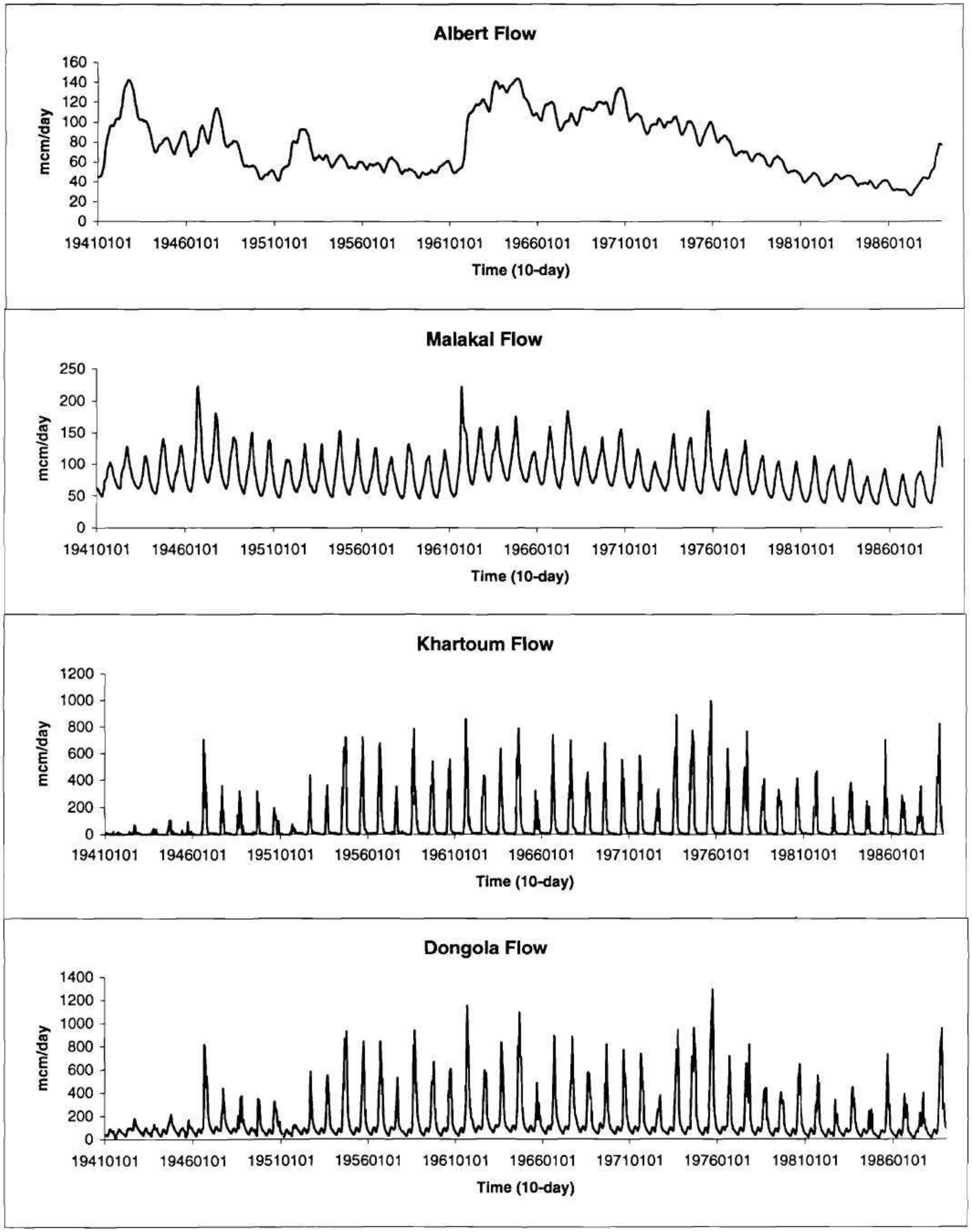


Figure C.3.5: Simulated Flow Sequences; Scenario I; Current Demand; 2020 Scenario

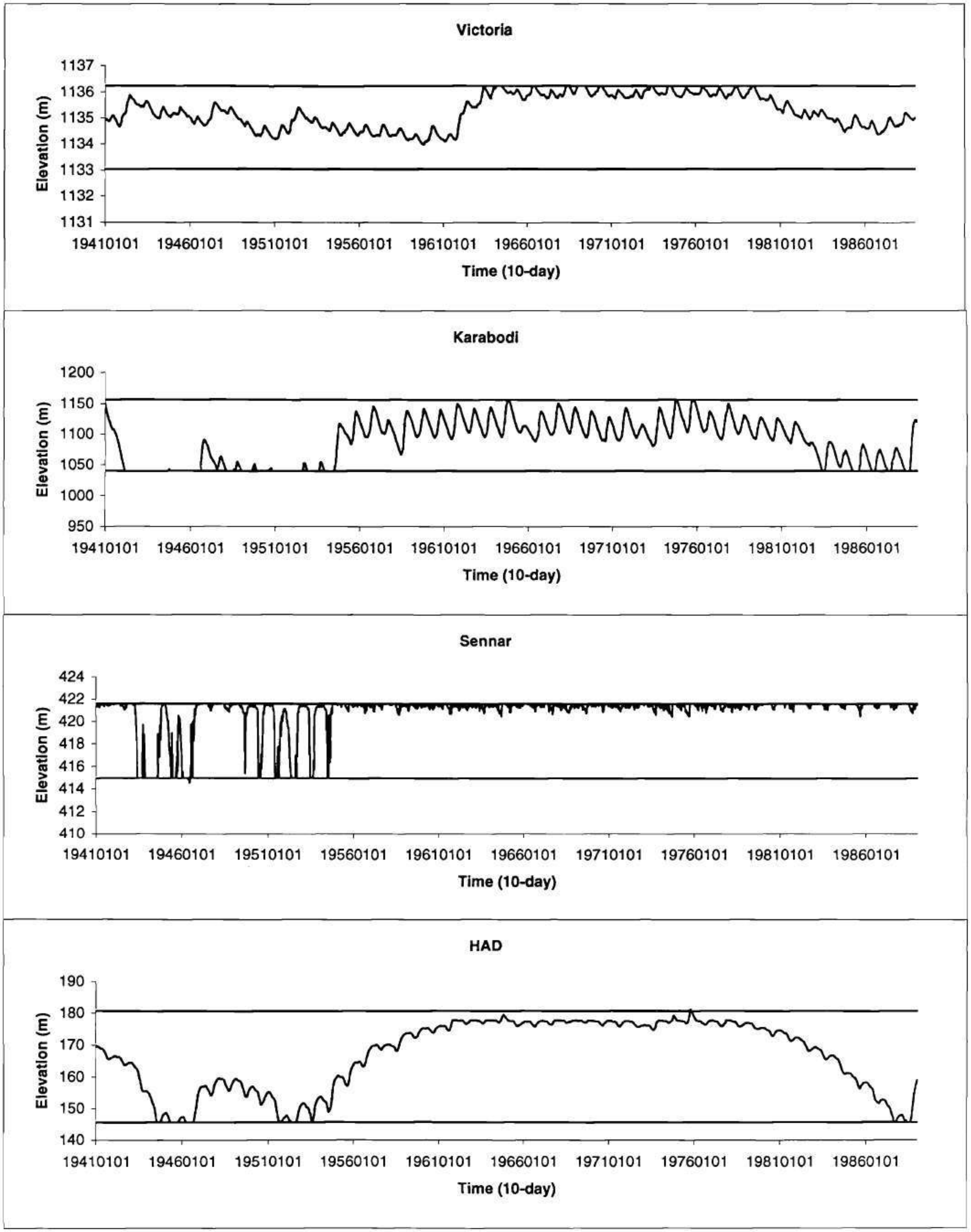


Figure C.3.6: Simulated Elevation Sequences for Selected Reservoirs; Scenario IV; Current Demand; 2020 Scenario

Table C.3.1: Nile Basin Assessment: White Nile Statistics (2020 Scenario)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	Inflow (bcm)	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23	16.23
	Net Evp. (bcm)	-10.20	-10.16	-10.12	-10.20	-10.16	-10.12	-10.33	-10.31	-10.29	-10.33	-10.31	-10.29
	Withdrawal (bcm)	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00
	Outflow (bcm)	27.52	25.27	23.01	27.52	25.27	23.01	27.01	24.62	22.22	27.01	24.62	22.22
Kyoga	Inflow (bcm)	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
	Net Evp. (bcm)	2.10	2.06	2.01	2.10	2.06	2.01	2.12	2.08	2.05	2.12	2.08	2.05
	Outflow (bcm)	28.14	25.94	23.73	28.14	25.94	23.73	27.61	25.26	22.92	27.61	25.26	22.92
Albert	Inflow (bcm)	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83
	Net Evp. (bcm)	3.68	3.67	3.65	3.68	3.67	3.65	3.71	3.70	3.68	3.71	3.70	3.68
	Outflow (bcm)	28.21	26.04	23.88	28.21	26.04	23.88	27.64	25.32	23.02	27.64	25.33	23.02
Torrents	Inflow (bcm)	11.26	11.26	11.26	11.26	11.26	11.26	11.26	11.26	11.26	11.26	11.26	11.26
Mongala	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Flow (bcm)	39.47	36.31	33.14	39.47	36.31	33.14	38.90	35.58	32.28	38.90	35.59	32.28
Sudd	Loss (bcm)	21.54	19.35	17.29	21.54	19.35	17.29	11.84	10.52	9.44	11.87	10.52	9.44
Sobat	Inflow (bcm)	13.32	13.32	13.32	13.32	13.32	13.32	18.07	18.07	18.07	18.07	18.07	18.07
Malakal	Flow (bcm)	31.25	30.28	29.16	31.25	30.28	29.16	45.13	43.14	40.91	45.09	43.14	40.92
Melut	Flow (bcm)	31.16	30.23	29.15	31.16	30.23	29.15	44.55	42.62	40.48	44.51	42.63	40.48
Gebel El Aulia	Withdrawal (bcm)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	Net Evp.(bcm)	3.77	3.50	3.47	3.77	3.73	3.69	3.98	3.91	3.84	3.98	3.91	3.84
	Outflow (bcm)	25.90	25.22	24.18	25.90	25.00	23.96	39.08	37.22	35.15	39.05	37.22	35.15
Bl. Nile at Khrtm.	Flow (bcm)	29.12	25.51	23.64	27.65	17.54	10.03	29.11	25.53	23.65	28.06	18.27	9.93
Atbara River	Flow (bcm)	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81
HAD	Inflow (bcm)	59.98	55.66	52.69	58.63	47.48	38.77	73.46	67.96	63.96	72.49	60.73	50.19
	Evap.(bcm)	9.61	7.73	6.59	9.38	5.82	5.00	11.24	10.35	9.36	11.40	8.78	5.58
	Withdrawal (bcm)	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00
	Outflow (bcm)	50.30	45.79	43.57	49.65	39.93	31.91	61.32	54.51	51.45	61.14	50.09	42.50

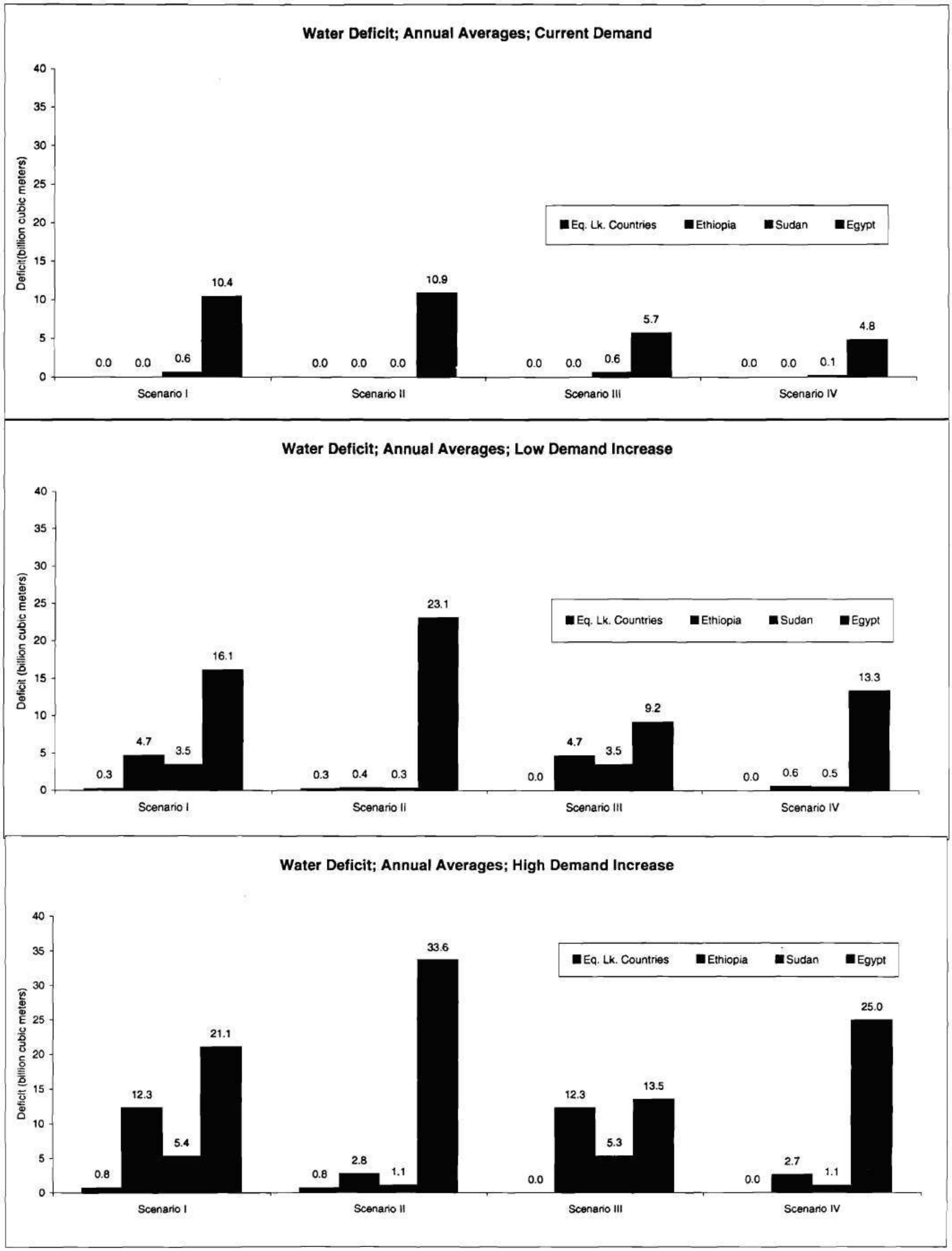
Table C.3.2: Nile Basin Assessment:Blue Nile Statistics (2020 Scenario)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Lake Tana	Inflow (bcm)	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	3.80	3.32	3.13	3.78	2.82	2.18	3.80	3.32	3.13	3.80	2.89	2.17
Karadobi	Inflow (bcm)	14.19	14.19	14.19	14.19	14.19	14.19	14.19	14.19	14.19	14.19	14.19	14.19
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	17.98	16.73	16.05	17.85	16.02	14.80	17.98	16.73	16.05	18.08	16.28	14.76
Mabil	Inflow (bcm)	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05	8.05
	Withdrawal (bcm)	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00	0.00	3.00	6.00
	Outflow (bcm)	26.03	23.24	21.91	25.76	21.04	17.64	26.03	23.24	21.91	25.98	21.40	17.49
Mendaia	Inflow (bcm)	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25	12.25
	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Outflow (bcm)	38.28	34.74	32.96	37.80	32.12	27.90	38.28	34.74	32.96	38.03	32.50	27.75
Border	Inflow (bcm)	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81
	Withdrawal (bcm)	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00	0.00	4.00	8.00
	Outflow (bcm)	46.09	40.72	38.30	45.32	35.80	28.49	46.09	40.72	38.30	45.54	36.28	28.34
Roseires	Inflow (bcm)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Outflow (bcm)	45.22	39.99	37.65	44.24	34.86	27.73	45.22	39.99	37.65	44.54	35.39	27.58
Sennar	Inflow (bcm)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Withdrawal (bcm)	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62	15.62	17.12	18.62
	Outflow (bcm)	28.91	25.19	23.27	27.40	16.98	9.24	28.90	25.22	23.27	27.83	17.73	9.13
Dinder+Rahad	Inflow (bcm)	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Bl. Nile at Khrtm.	Flow (bcm)	29.12	25.51	23.64	27.65	17.54	10.03	29.11	25.53	23.65	28.06	18.27	9.93
K. Girba	Inflow (bcm)	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47	9.47
	Withdrawal (bcm)	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.38
	Outflow (bcm)	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81	7.81

Appendix D

"2050" Climate Assessment Results

The figures and tables included in this appendix follow the same format as those of Appendices B and C. As a general comment, the "2050" climate scenario is drier than the previous two, especially over the southern Nile. This exacerbates deficits, reduces energy generation, and causes more frequent low flows. These are clearly reflected on the basin response measures included in this appendix.



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure D.1.1: Deficit; Annual Average; 2050 Scenario

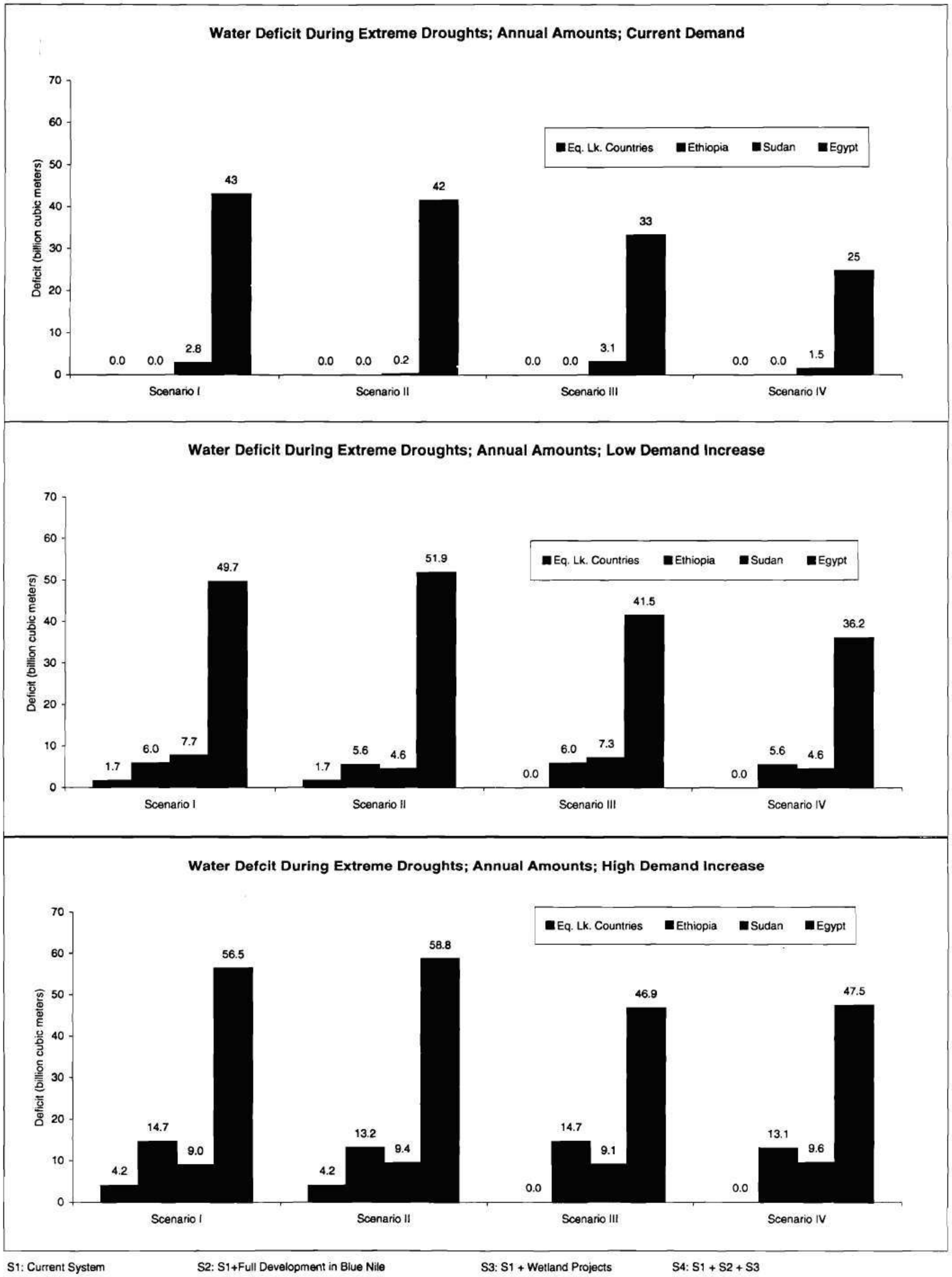


Figure D.1.2: Deficit During Extreme Droughts; Annual Amounts; 2050 Scenario

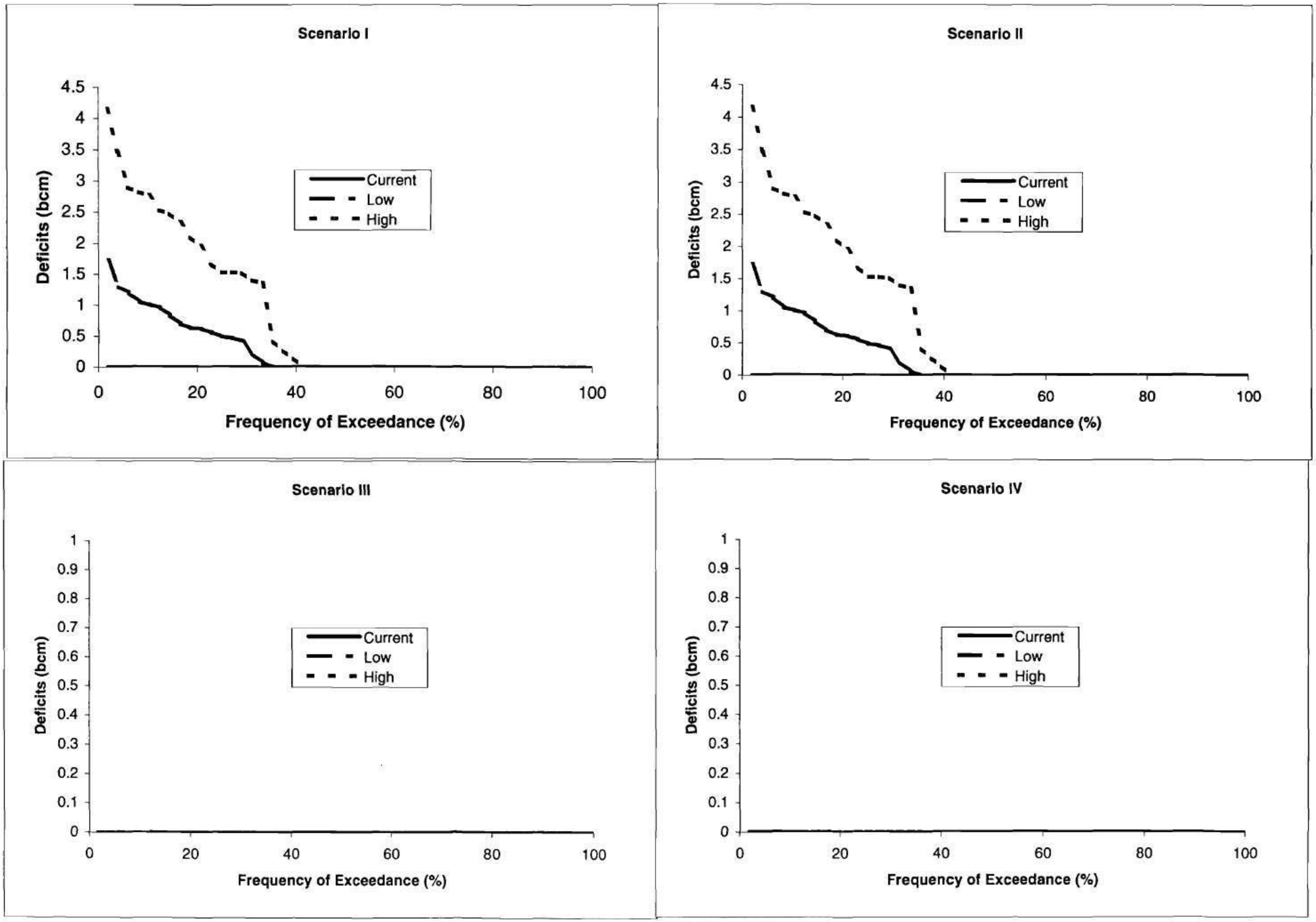


Figure D.1.3a: Annual Deficit Frequency Curves; Equatorial Lake Region; 2050 Scenario

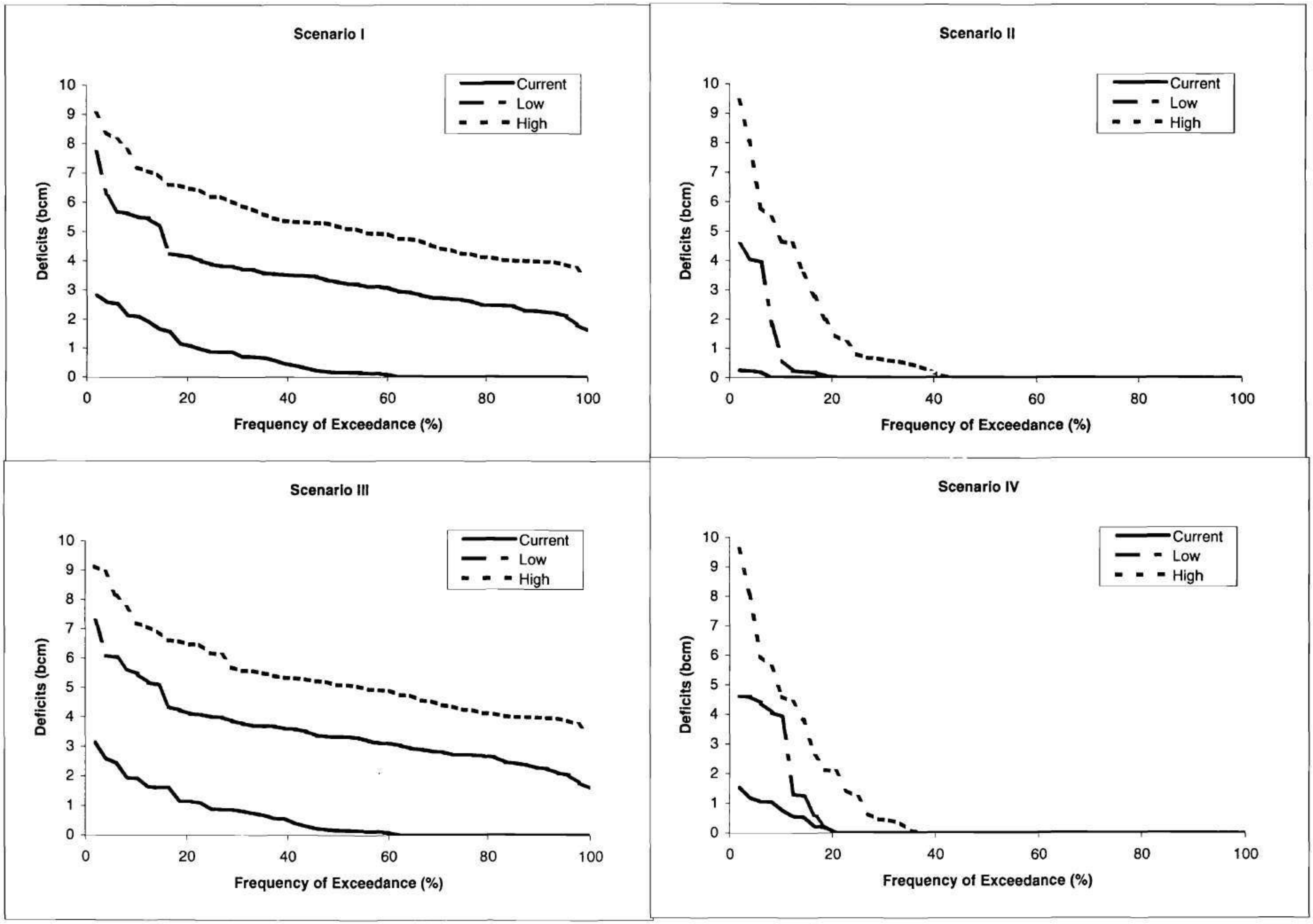


Figure D.1.3b: Annual Deficit Frequency Curves; Sudan; 2050 Scenario

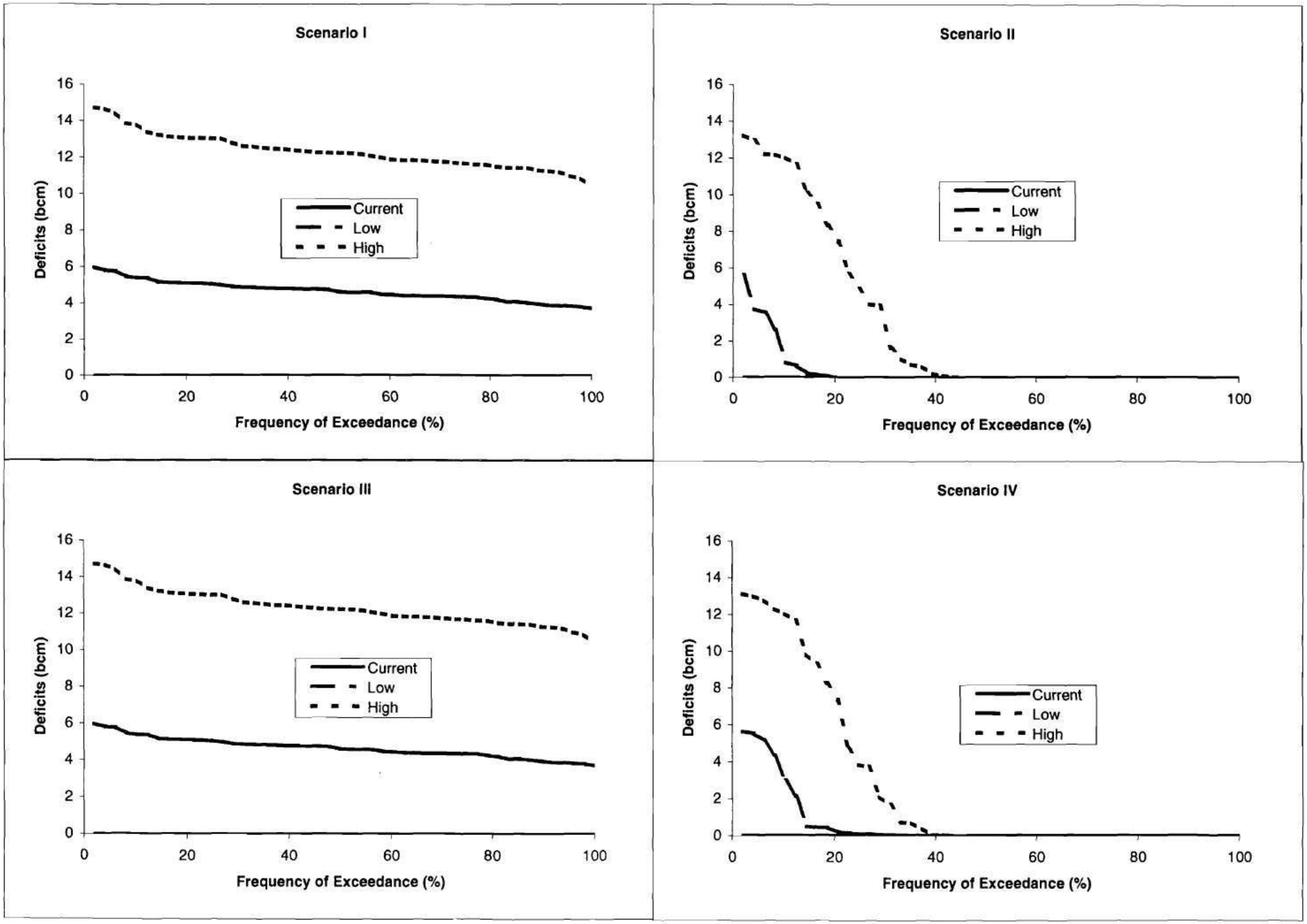


Figure D.1.3c: Annual Deficit Frequency Curves; Ethiopia/EritreaSudan; 2050 Scenario

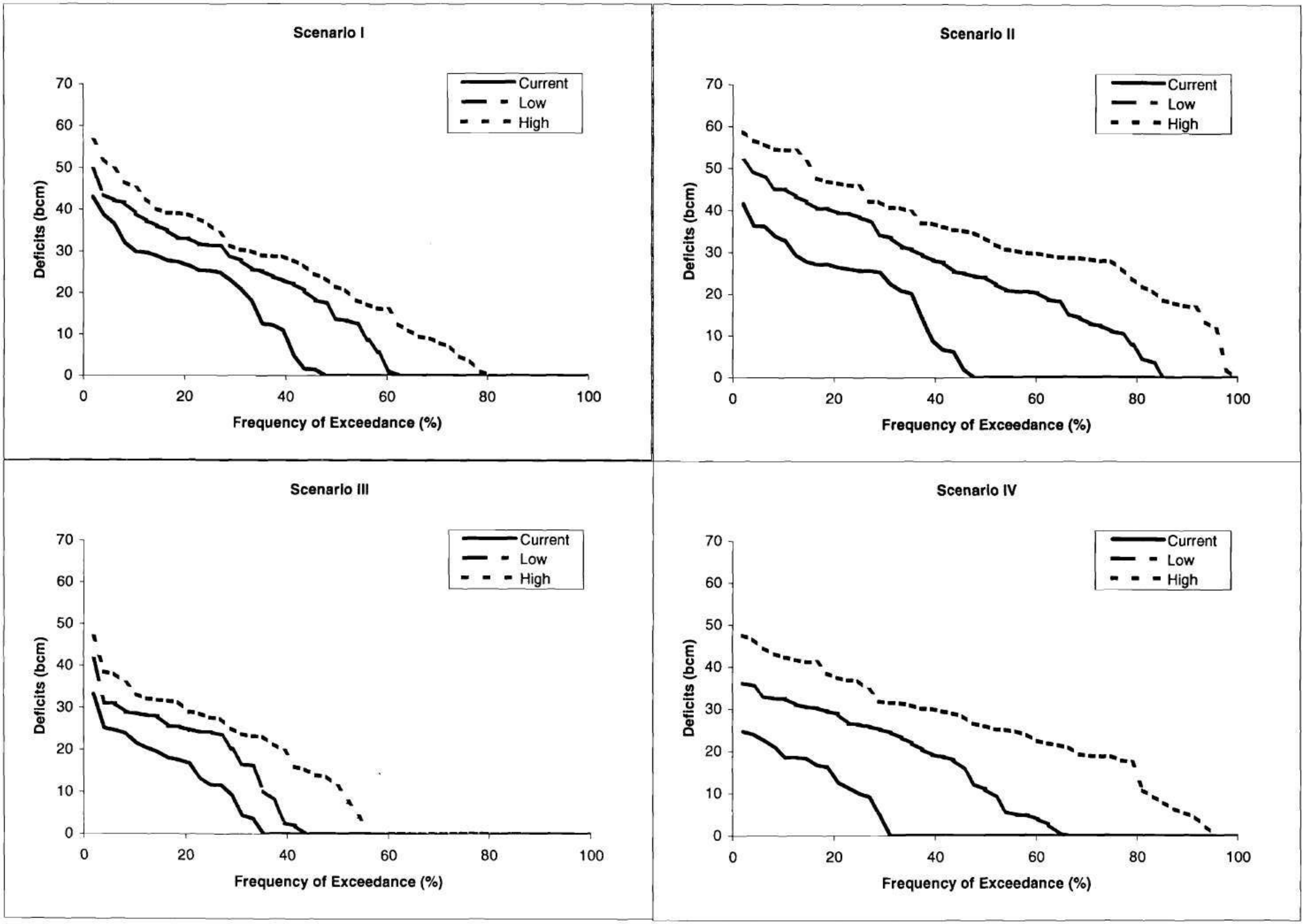
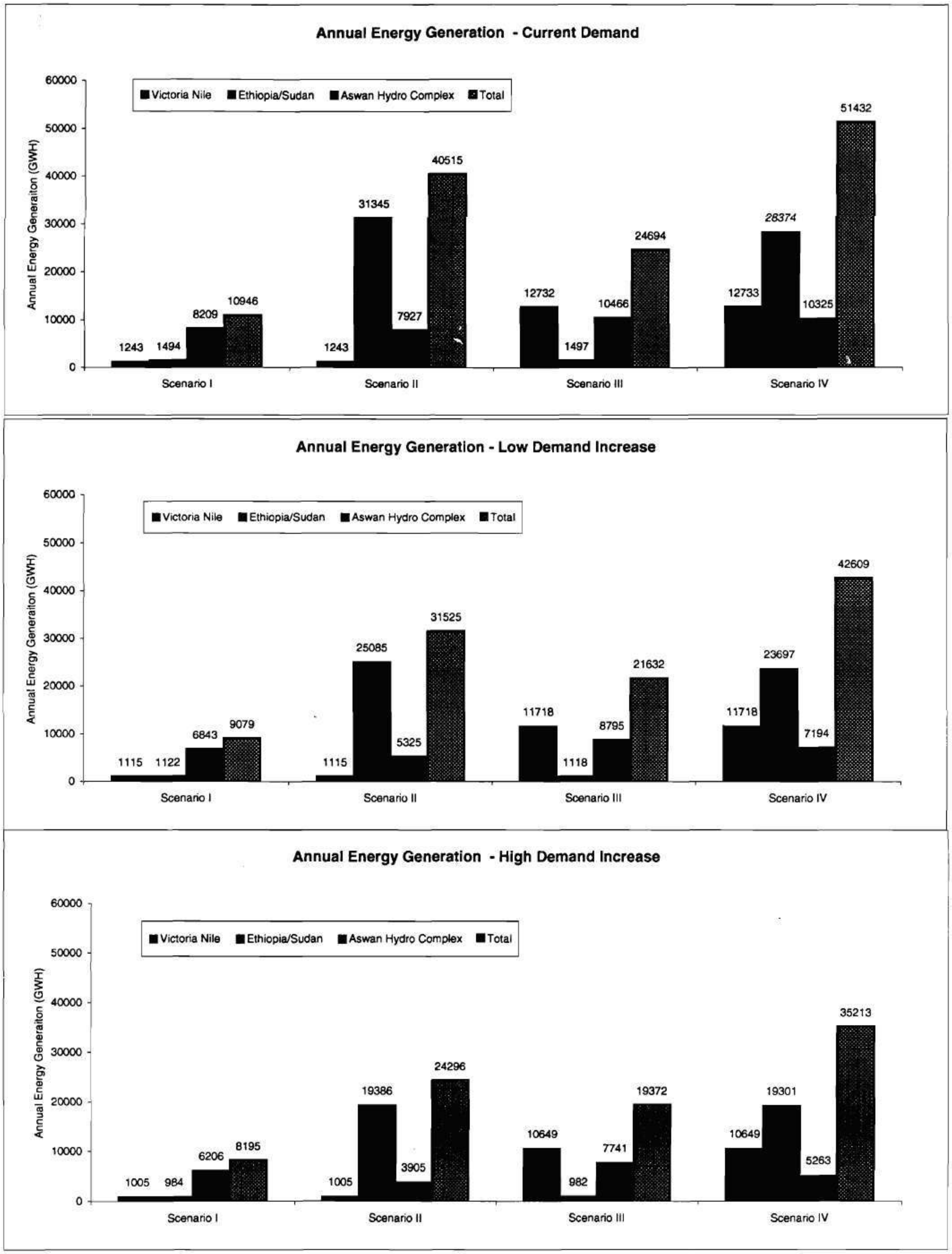


Figure D.1.3d: Annual Deficit Frequency Curves; Egypt;
2050 Scenario

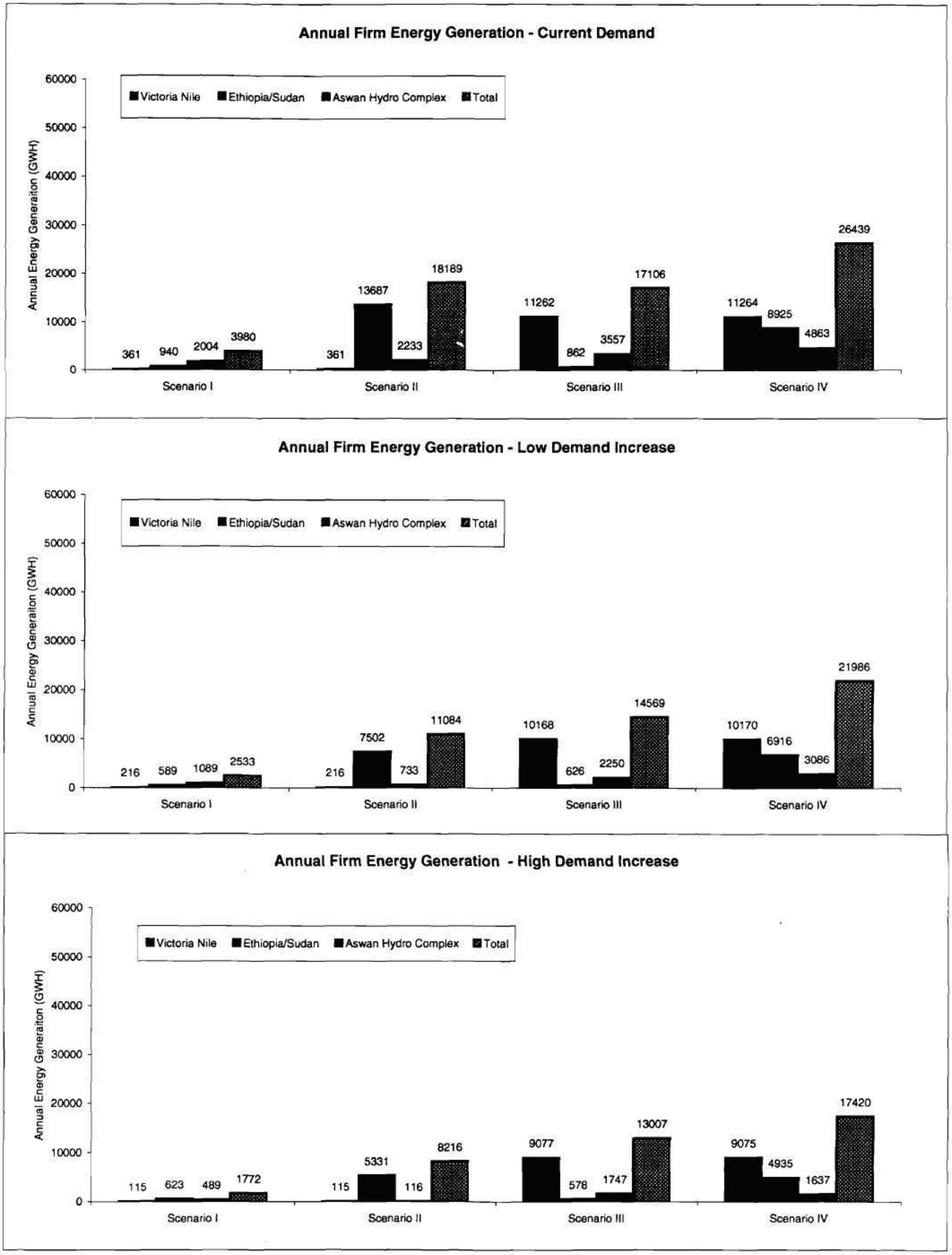
Table D.1: Nile Basin Assessment: Annual Average Deficit Statistics (2050 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	0.00	0.26	0.78	0.00	0.26	0.78	0.00	0.00	0.00	0.00	0.00	0.00
Mongala	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Gabel Aulia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tana	0.00	0.53	1.34	0.00	0.02	0.23	0.00	0.53	1.34	0.00	0.04	0.23
Karadobi	0.00	0.23	0.74	0.00	0.02	0.21	0.00	0.23	0.74	0.00	0.04	0.22
Mabil	0.00	1.47	3.84	0.00	0.12	0.99	0.00	1.47	3.84	0.00	0.20	0.87
Mendaia	0.00	0.26	0.81	0.00	0.04	0.23	0.00	0.26	0.81	0.00	0.05	0.23
Border	0.00	2.18	5.58	0.00	0.18	1.11	0.00	2.18	5.58	0.00	0.25	1.12
Sennar	0.57	3.46	5.32	0.00	0.31	1.07	0.57	3.49	5.33	0.13	0.50	1.10
Girba	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
HAD Upstream	0.00	0.16	0.32	0.00	0.13	0.32	0.00	0.01	0.04	0.00	0.00	0.04
HAD Downstream	10.45	15.91	20.80	10.89	22.95	33.32	5.71	9.15	13.49	4.76	13.33	24.97



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure D.2.1: Annual Average Energy Generation; 2050 Scenario



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure D.2.2: Annual Firm Energy Generation; 2050 Scenario

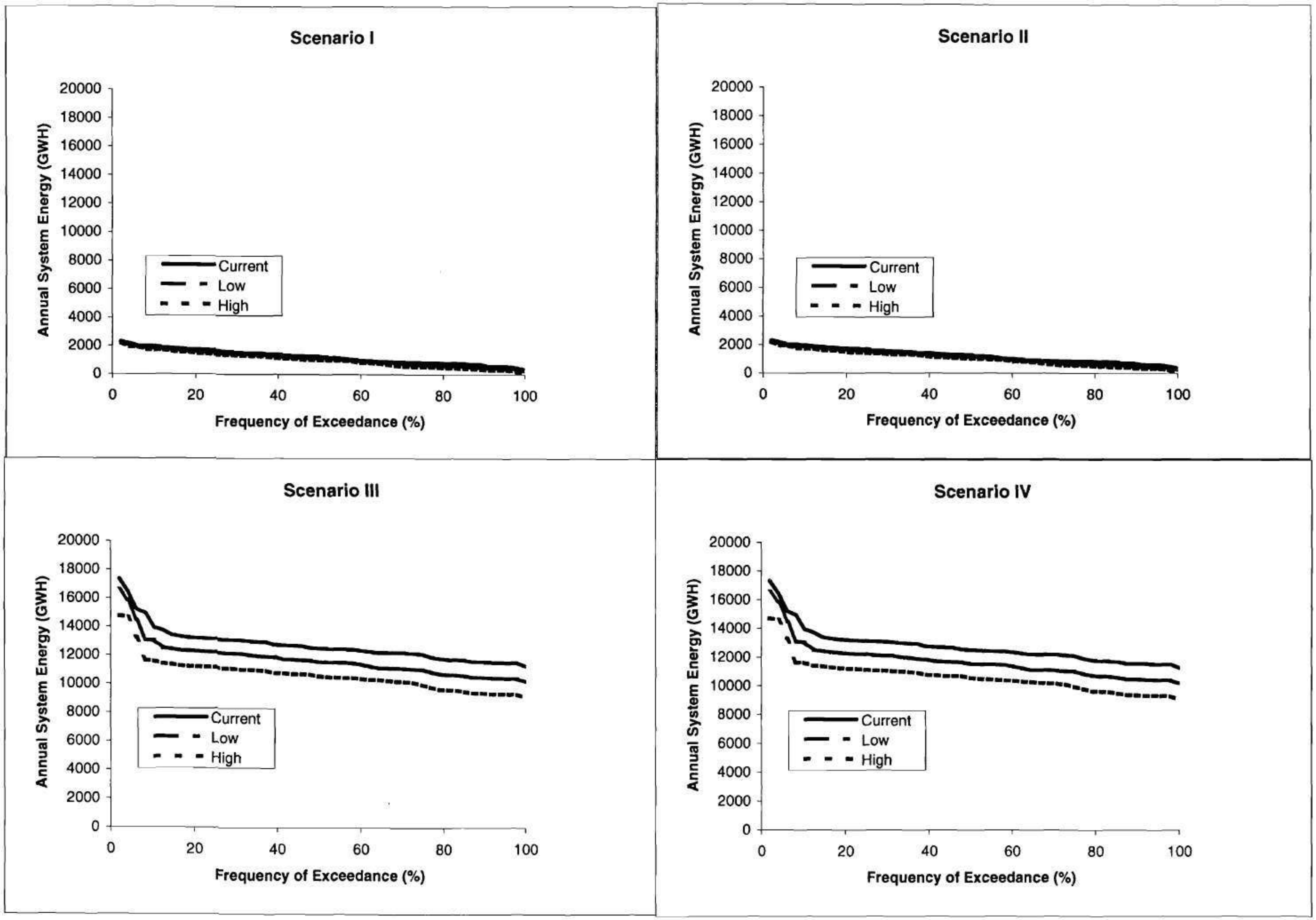


Figure D.2.3a: Annual Energy Frequency Curves; Victoria Nile; 2050 Scenario

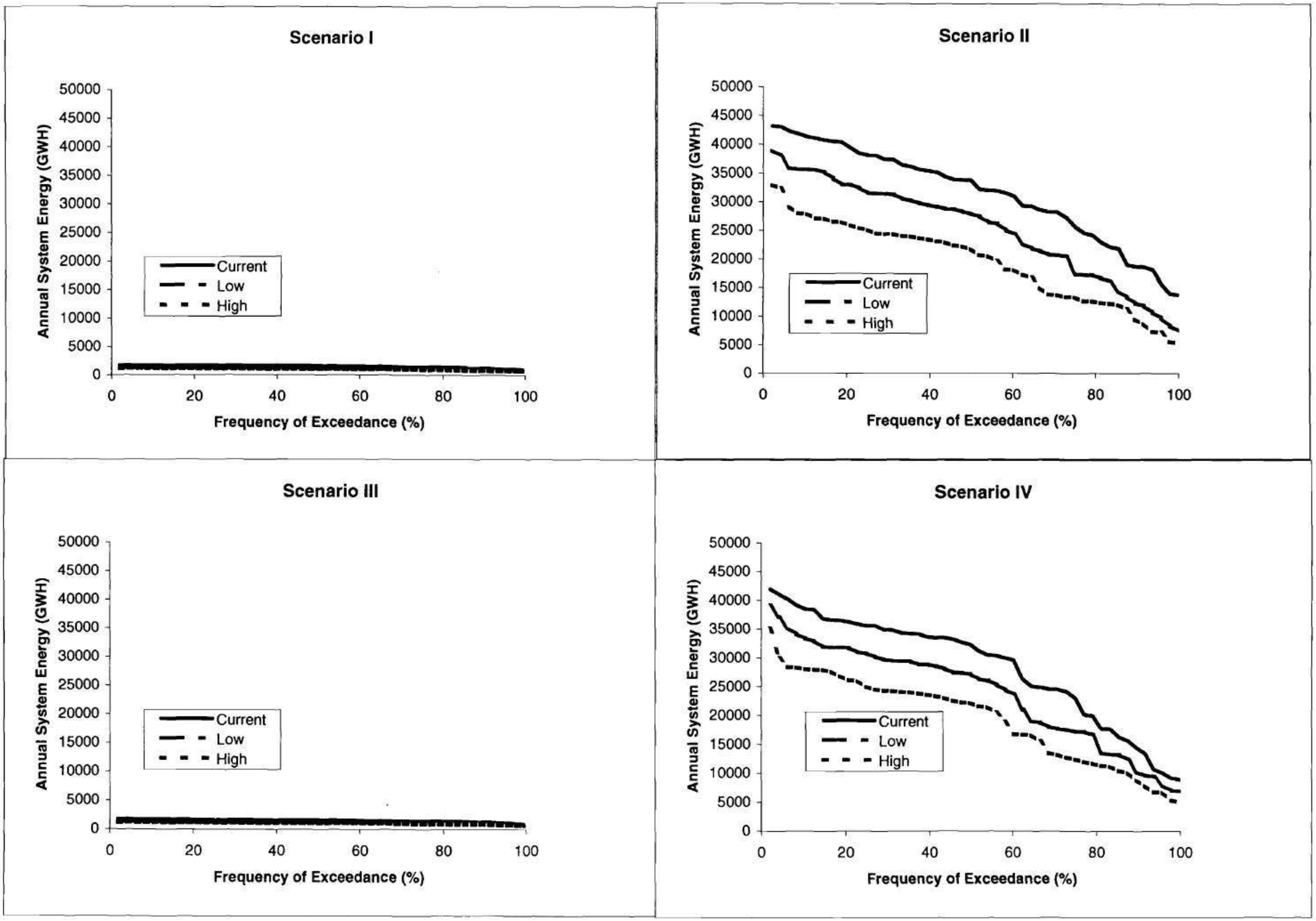


Figure D.2.3b: Annual Energy Frequency Curves; Ethiopia/Sudan; 2050 Scenario

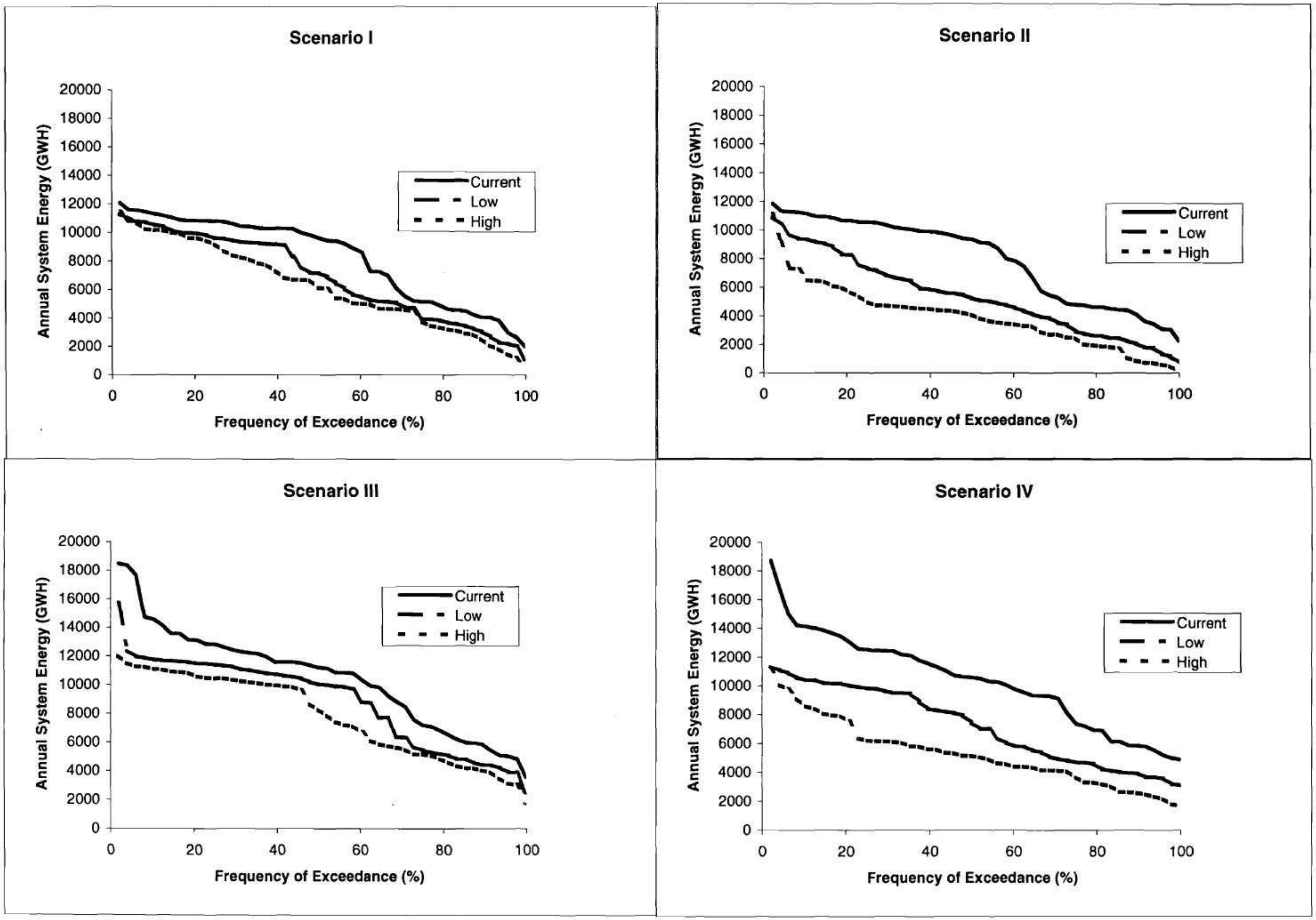


Figure D.2.3c: Annual Energy Frequency Curves; HAD Hydro Complex; 2050 Scenario

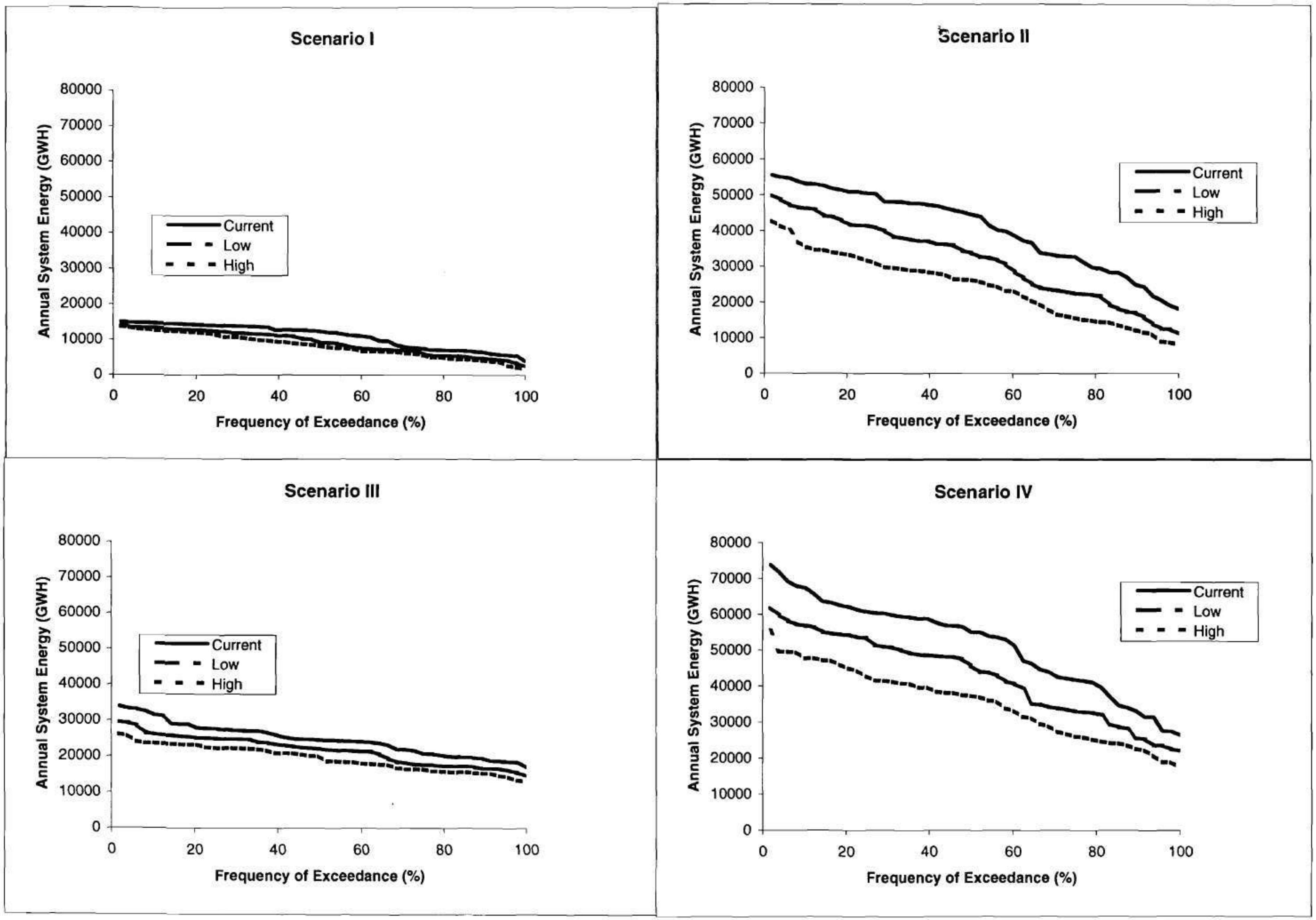


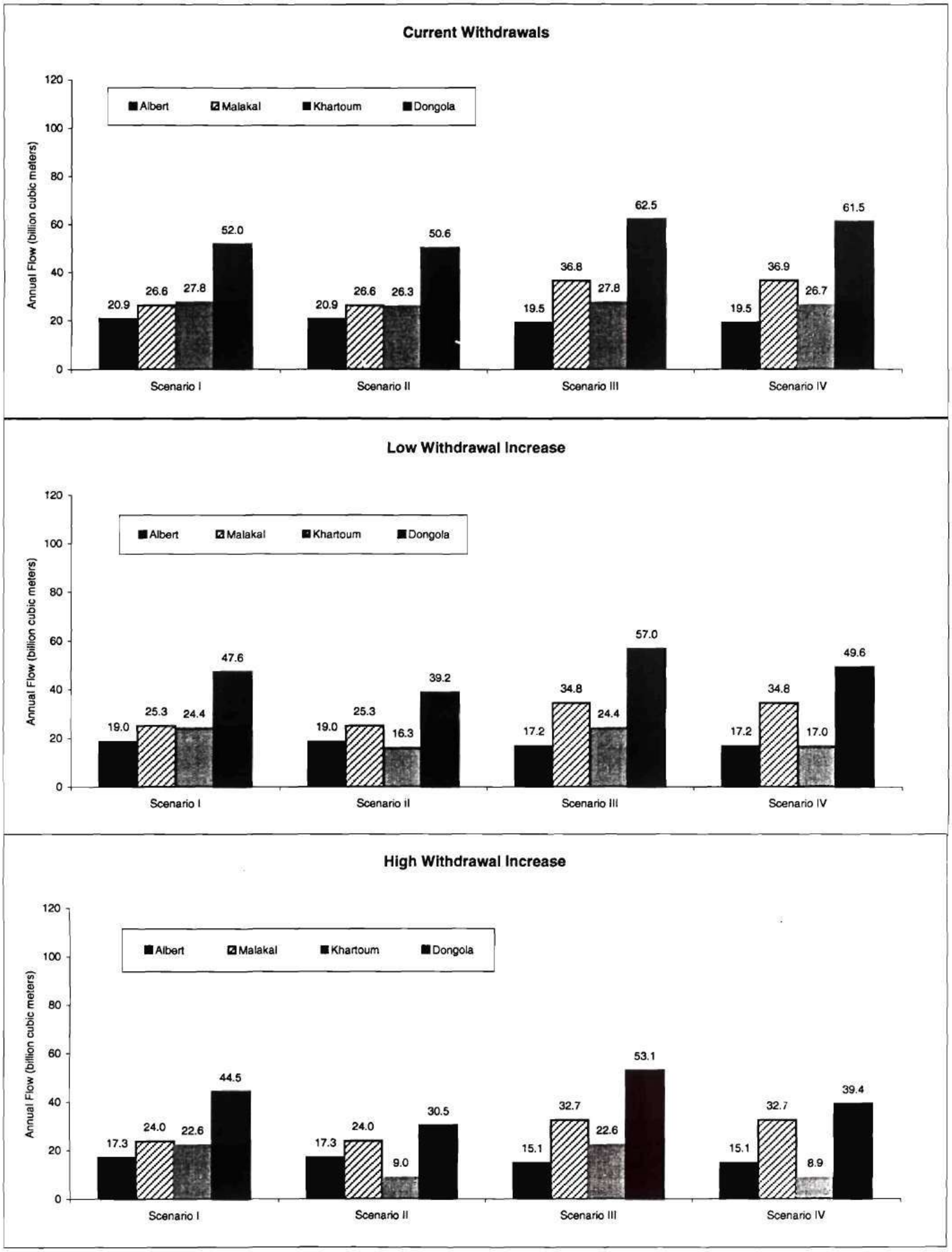
Figure D.2.3d: Annual Energy Frequency Curves; Total System; 2050 Scenario

Table D.2a: Nile Basin Assessment: Average Annual Energy (GWH) Statistics (2050 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Owen Falls	1243	1115	1005	1243	1115	1005	1231	1090	950	1232	1090	950
Bujagali	0	0	0	0	0	0	1061	939	818	1061	939	818
Kalagala	0	0	0	0	0	0	1297	1146	998	1298	1146	998
Kamdini	0	0	0	0	0	0	1116	1000	887	1117	1000	887
Ayago South	0	0	0	0	0	0	2460	2245	2015	2460	2245	2015
Ayago North	0	0	0	0	0	0	2051	2051	2051	2051	2051	2051
Murchison	0	0	0	0	0	0	3514	3248	2929	3515	3248	2930
Subtotal	1243	1115	1005	1243	1115	1005	12732	11718	10649	12733	11718	10649
Lake Tana	0	0	0	1524	1237	997	0	0	0	1497	1247	981
Karadobi	0	0	0	6129	4698	2951	0	0	0	3682	3165	2680
Mabil	0	0	0	5610	4253	2964	0	0	0	4822	3964	3149
Mendaia	0	0	0	9333	7881	6818	0	0	0	9424	7994	6727
Border	0	0	0	6678	5179	4076	0	0	0	6752	5310	4075
Subtotal	0	0	0	29275	23247	17807	0	0	0	26177	21680	17613
Roseires	1348	1030	906	1904	1678	1437	1350	1027	905	2036	1862	1546
Sennar	112	57	43	131	125	108	112	57	43	127	121	108
K. Girba	34	35	35	34	34	34	34	34	34	34	34	34
Subtotal	1494	1122	984	2070	1837	1579	1497	1118	982	2197	2017	1688
HAD (GWH)	8209	6843	6206	7927	5325	3905	10466	8795	7741	10325	7194	5263
Total	**10946**	**9079**	**8195**	**40515**	**31525**	**24296**	**24694**	**21632**	**19372**	**51432**	**42609**	**35213**

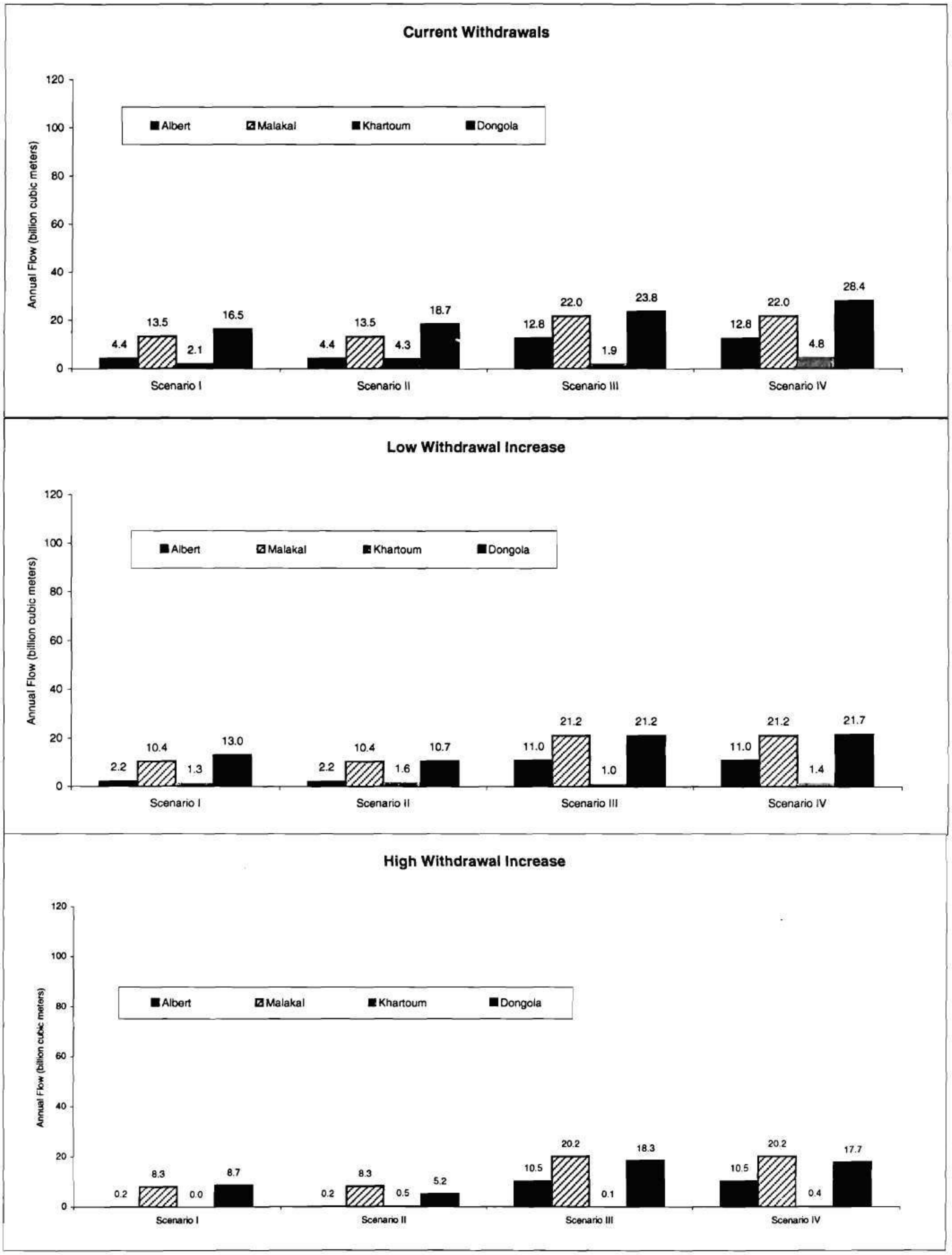
Table D.2b: Nile Basin Assessment: Annual Firm Energy (GWH) Statistics (2050 Scenario)

Locations	Scenario I			Scenario II			Scenario III			Scenario IV		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**	**Low**	**Medium**	**High**
Owen Falls	361	216	115	361	216	115	974	851	731	975	851	731
Bujagali	0	0	0	0	0	0	841	736	635	841	736	635
Kalagala	0	0	0	0	0	0	1024	896	773	1024	896	773
Kamdini	0	0	0	0	0	0	928	817	707	928	817	707
Ayago South	0	0	0	0	0	0	2135	1880	1626	2135	1880	1626
Ayago North	0	0	0	0	0	0	2050	2050	2047	2050	2050	2047
Murchison	0	0	0	0	0	0	3118	2746	2376	3119	2747	2375
Subtotal	361	216	115	361	216	115	11070	9977	8895	11072	9978	8894
Lake Tana	0	0	0	695	517	459	0	0	0	718	526	362
Karadobi	0	0	0	157	49	1	0	0	0	0	0	0
Mabil	0	0	0	2533	82	37	0	0	0	0	0	7
Mendaia	0	0	0	4818	3195	2127	0	0	0	3632	3094	2038
Border	0	0	0	3435	2134	1420	0	0	0	2733	2025	1394
Subtotal	0	0	0	11637	5977	4045	0	0	0	7083	5646	3801
Roseires	865	557	596	1544	764	519	784	593	554	1055	763	510
Sennar	54	11	0	131	45	12	57	12	3	74	38	12
K. Girba	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	919	568	596	1675	809	531	841	605	557	1129	801	522
HAD (GWH)	2004	1089	489	2233	733	116	3557	2250	1747	4863	3086	1637
Total	**3283**	**1873**	**1200**	**15907**	**7735**	**4807**	**15468**	**12831**	**11199**	**24147**	**19511**	**14854**



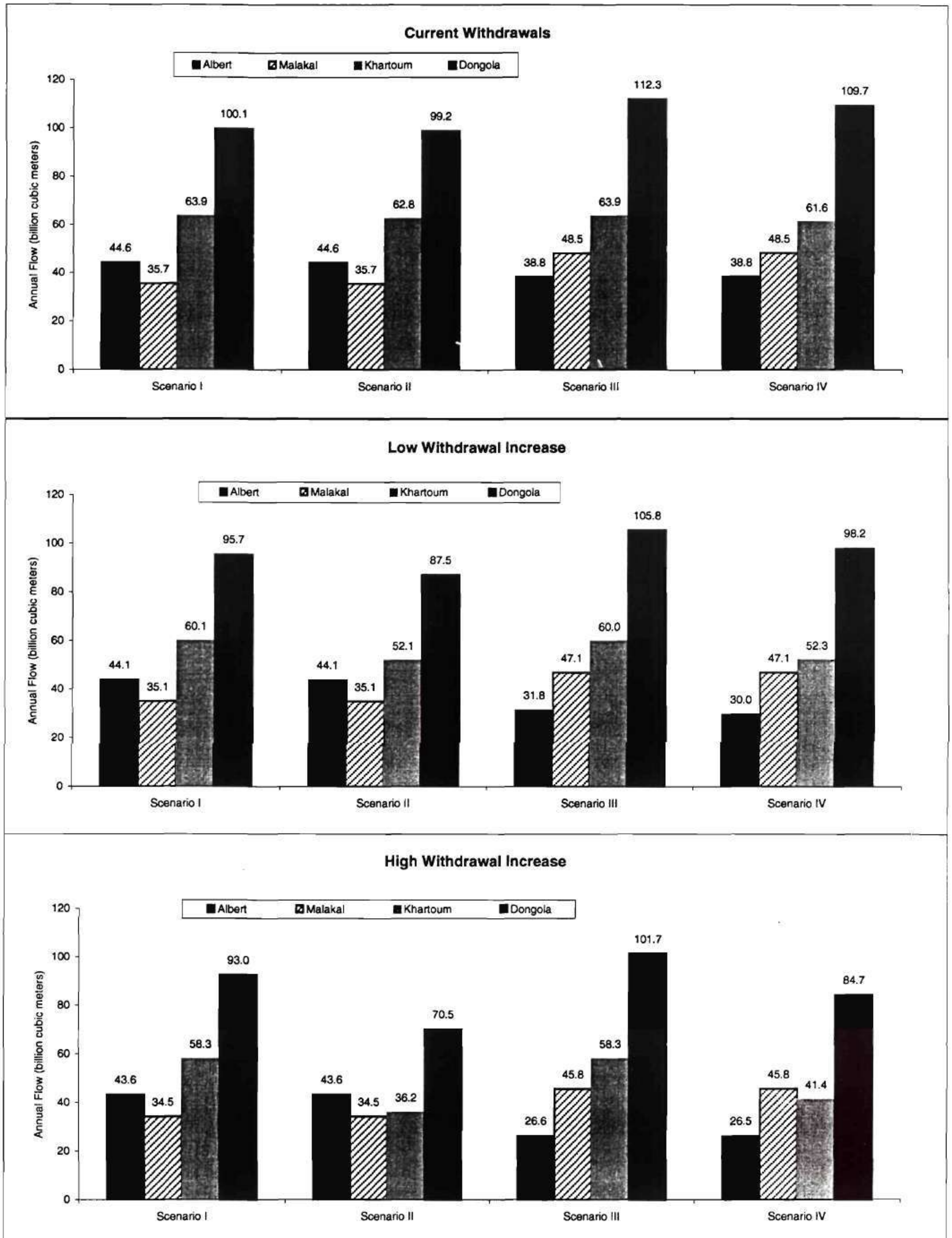
S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure D.3.1: Annual Average Flows at Representative Basin Locations; 2050 Scenario



S1: Current System   S2: S1+Full Development in Blue Nile   S3: S1 + Wetland Projects   S4: S1 + S2 + S3

Figure D.3.2: Minimum Annual Flows at Representative Basin Locations; 2050 Scenario



S1: Current System S2: S1+Full Development in Blue Nile S3: S1 + Wetland Projects S4: S1 + S2 + S3

Figure 3.3: Maximum Annual Flows at Representative Basin Locations; 2050 Scenario

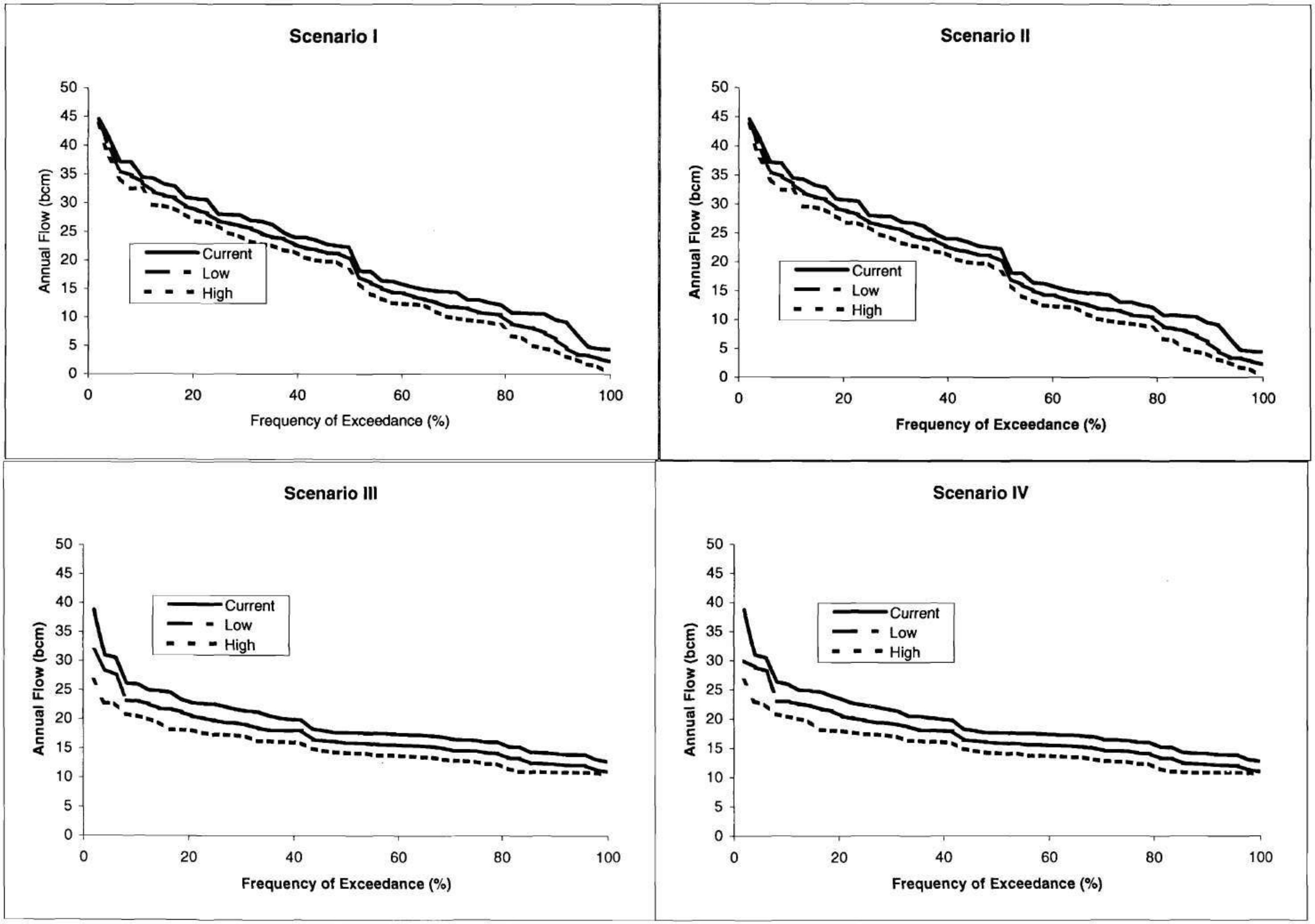


Figure D.3.4a: Flow Frequency Curves; Albert Outflows; 2050 Scenario

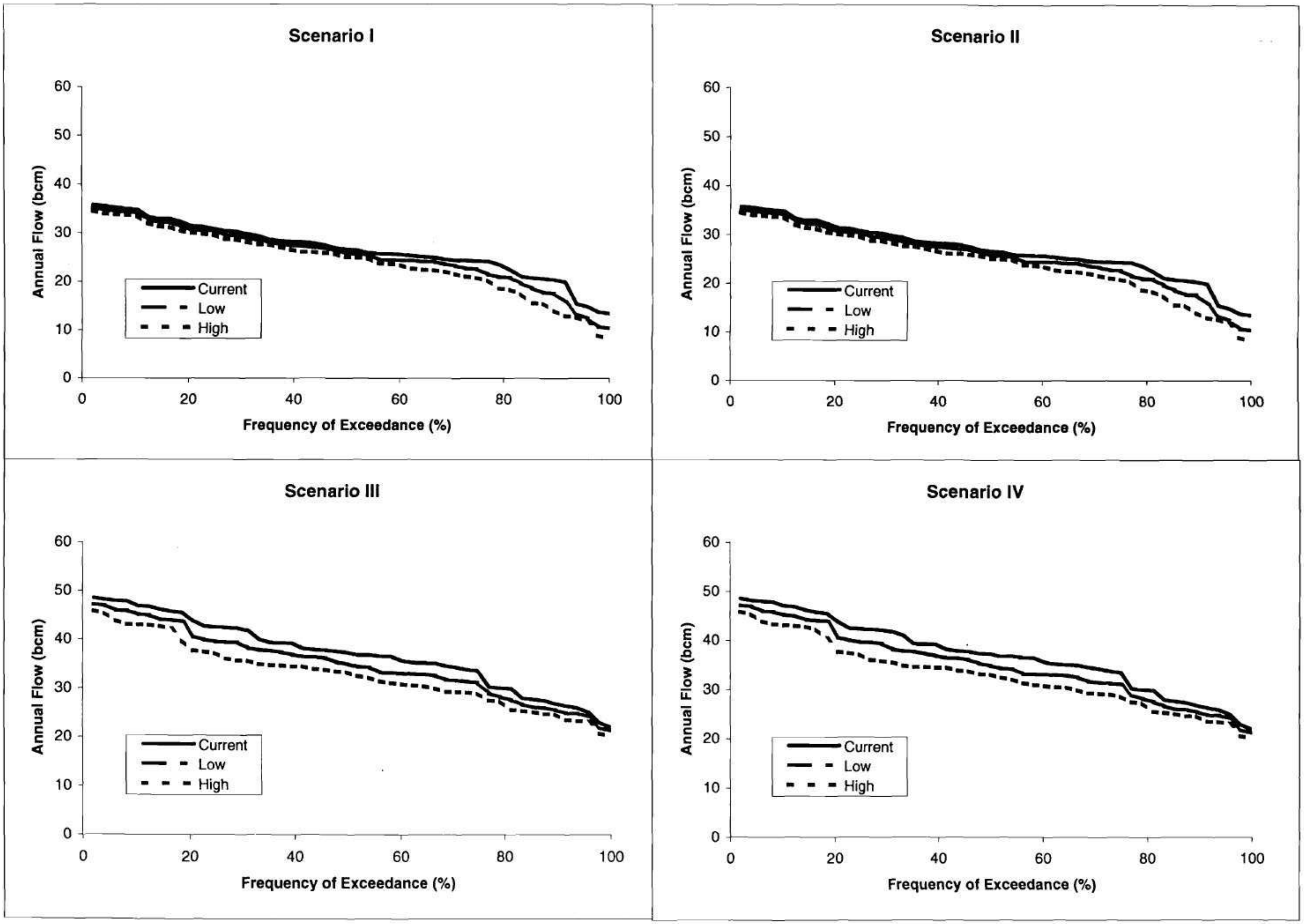


Figure D.3.4b: Flow Frequency Curves; Malakal flows; 2050 Scenario

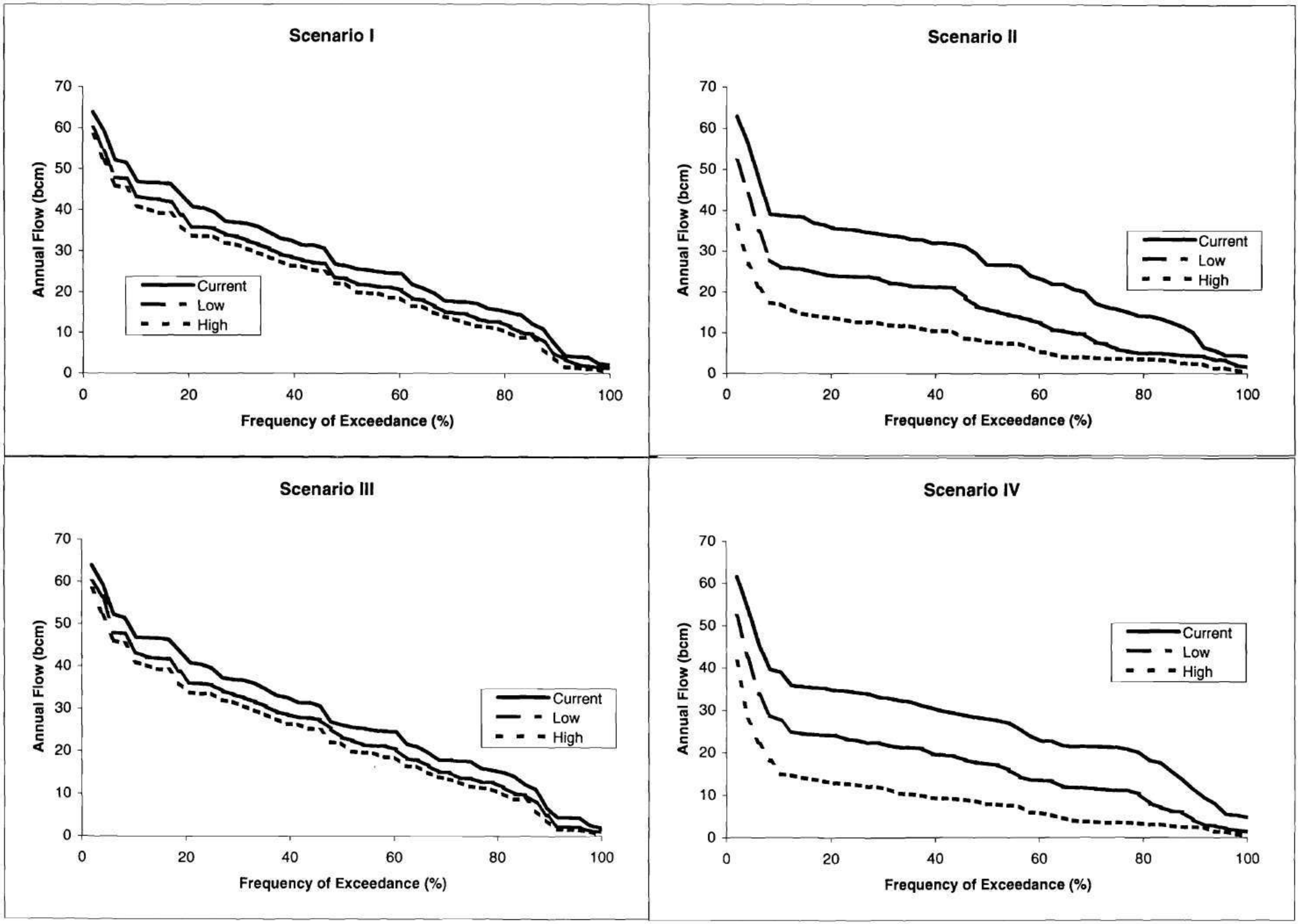


Figure D.3.4c: Flow Frequency Curves; Khartoum Flows; 2050 Scenario

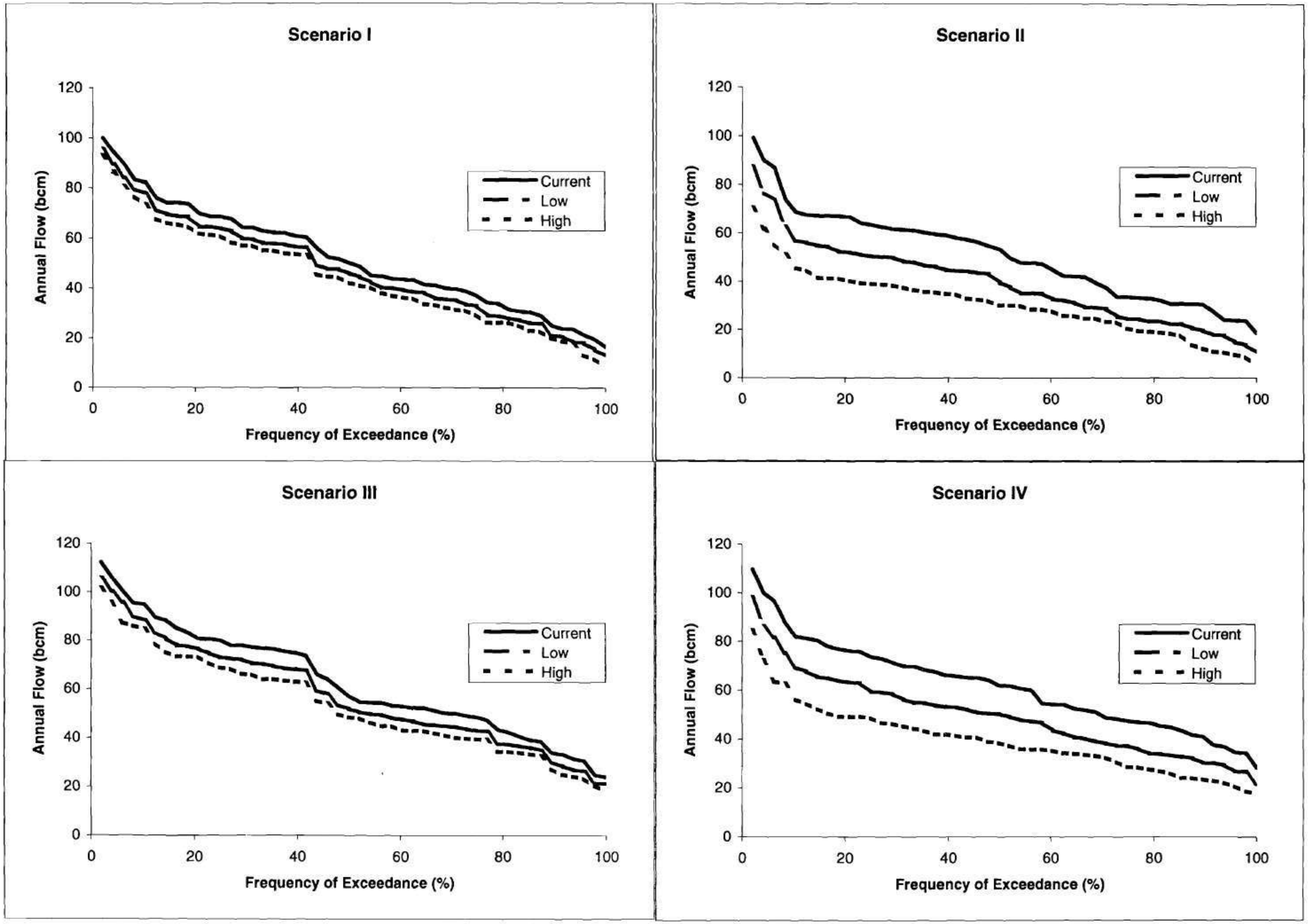


Figure D.3.4d: Flow Frequency Curves; Dongola Flows; 2050 Scenario

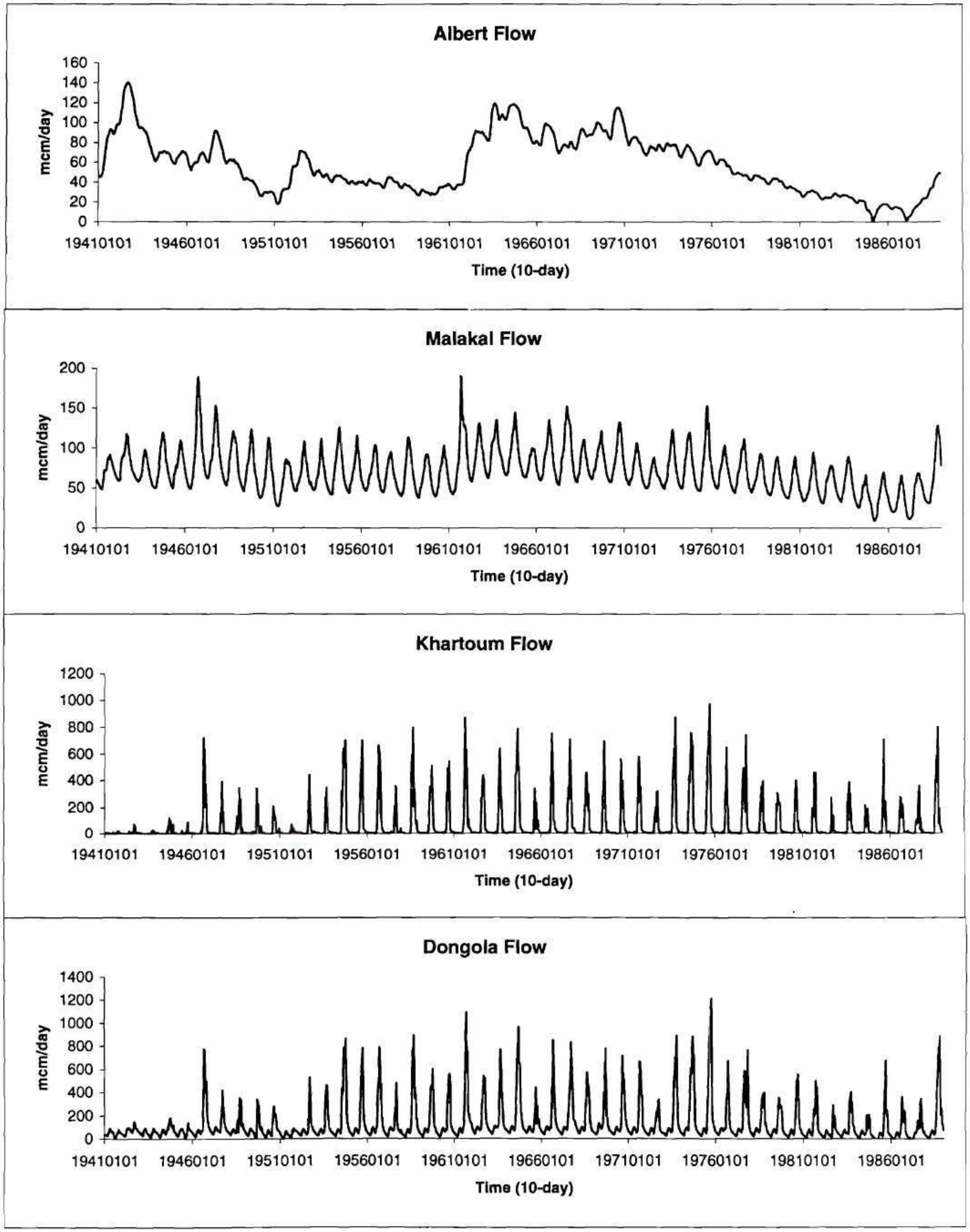


Figure D.3.5: Simulated Flow Sequences; Scenario 1; Current Demand; 2050 Scenario

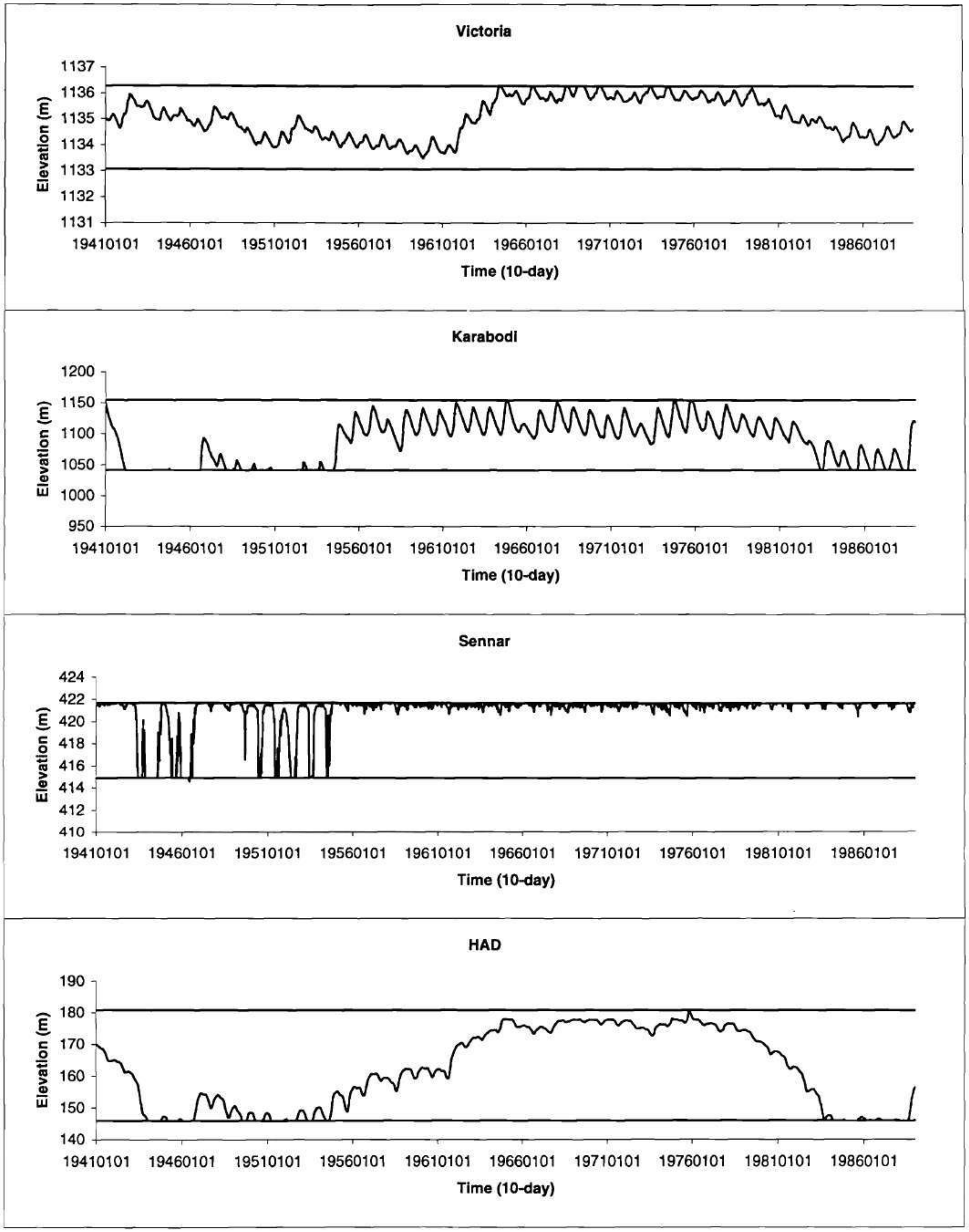


Figure D.3.6: Simulated Elevation Sequences for Selected Reservoirs; Scenario IV; Current Demand; 2050 Scenario

Table D.3.1: Nile Basin Assessment: White Nile Statistics (2050 Scenario)

Locations	Quantity (Units)	Scenario I			Scenario II			Scenario III			Scenario IV		
		Current	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**	**Current**	**Low**	**High**
Victoria	Inflow (bcm)	16.60	16.60	16.60	16.60	16.60	16.60	16.60	16.60	16.60	16.60	16.60	16.60
	Net Evp. (bcm)	-2.87	-2.87	-2.87	-2.87	-2.87	-2.87	-2.93	-2.91	-2.90	-2.93	-2.91	-2.90
	Withdrawal (bcm)	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00	0.00	2.50	5.00
	Outflow (bcm)	21.29	19.14	17.28	21.29	19.14	17.28	19.97	17.64	15.36	19.97	17.64	15.36
Kyoga	Inflow (bcm)	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
	Net Evp. (bcm)	2.40	2.33	2.27	2.40	2.33	2.27	2.46	2.41	2.34	2.46	2.41	2.34
	Outflow (bcm)	21.27	19.29	17.59	21.27	19.29	17.59	19.86	17.60	15.42	19.86	17.60	15.42
Albert	Inflow (bcm)	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73	3.73
	Net Evp. (bcm)	4.08	4.06	4.04	4.08	4.06	4.04	4.12	4.09	4.07	4.11	4.10	4.07
	Outflow (bcm)	20.92	18.96	17.29	20.92	18.96	17.29	19.46	17.24	15.13	19.46	17.24	15.13
Torrents	Inflow (bcm)	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78	9.78
Mongala	Withdrawal (bcm)	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00	0.00	1.00	2.00
	Flow (bcm)	30.70	27.75	25.10	30.70	27.75	25.10	29.24	26.02	22.91	29.24	26.02	22.91
Sudd	Loss (bcm)	15.65	14.02	12.65	15.65	14.02	12.65	8.26	7.20	6.24	8.26	7.17	6.21
Sobat	Inflow (bcm)	11.42	11.42	11.42	11.42	11.42	11.42	16.17	16.17	16.17	16.17	16.17	16.17
Malakal	Flow (bcm)	26.47	25.14	23.87	26.47	25.14	23.87	37.15	34.98	32.84	37.15	35.02	32.86
Melut	Flow (bcm)	26.56	25.27	24.04	26.56	25.27	24.04	36.85	34.76	32.70	36.86	34.79	32.72
Gebel El Aulia	Withdrawal (bcm)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
	Net Evp.(bcm)	3.73	3.35	3.34	3.73	3.70	3.68	3.75	3.68	3.61	3.75	3.68	3.61
	Outflow (bcm)	21.33	20.42	19.21	21.33	20.07	18.86	31.60	29.58	27.59	31.61	29.62	27.61
Bl. Nile at Khrtm.	Flow (bcm)	27.83	24.37	22.58	26.28	16.31	9.01	27.83	24.40	22.60	26.72	16.96	8.88
Atbara River	Flow (bcm)	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
HAD	Inflow (bcm)	52.01	47.57	44.52	50.60	39.19	30.52	62.52	57.03	53.14	61.50	49.61	39.39
	Evap.(bcm)	7.37	6.13	5.70	6.76	5.16	4.86	9.91	8.11	6.57	9.47	5.89	4.95
	Withdrawal (bcm)	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00	0.00	2.50	3.00
	Outflow (bcm)	45.05	39.59	36.70	44.61	32.55	24.18	52.35	46.69	44.01	52.63	42.17	32.53